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IN MEMORIAM.

DR. JOHN HEWETSON.

1867-1910.

The men of the first few years of the existence of this hospital formed a very happy band—young and eager, with a great problem before them, too great, indeed, to be fully appreciated by us. It was a motley group that the gift of a new foundation in medicine had brought together, strangers to each other, strangers in a strange city; yet there was something in the air, and something in the spirit of the place that quickly ripened a mutual trust into good fellowship. The "lead" already given by that great triumvirate, Martin, Remsen and Welch, with Mr. Gilman's strong personality and intense interest in the hospital (which he had opened for the trustees) made the "running" comparatively easy. It has often been remarked that the reputation of the Johns Hopkins Medical School has been made by its young men, to which I may note incidentally my shelves bear weighty testimony in the 12 volumes, with the 500 papers of the graduates of the school during the first 8 years. We were singularly fortunate in the senior assistants with whom the work began, Councilman, Lafleur, Brockway and Robb. I have forgotten how it was that Lafleur came to us from Montreal, probably through my friends Ross and MacDonnell, but it proved a very happy selection, and the "Dane," as we loved to call him, gave a certain *cachet* to the position, which his successors have been keen to appreciate. In the first year we had for house physicians Toulmin from Philadelphia, Reese from Baltimore, and "Al" Scott from Philadelphia, all congenial spirits and enthusiastic workers. Reese was cut off by tuberculosis at the very outset of a brilliant career; while his many friends had to lament Scott's untimely death last year. As the work grew the following year Simon and Hoch came into the house. Then, in the summer of 1891, Thayer joined the staff, and in October succeeded Lafleur as first assistant. In 1890 there came to us, probably through the influence of Lafleur, John Hewetson from McGill, who had just finished a term of residence at the Montreal General Hospital. I have just had the sad news of his death, and wish to pay a brief tribute to his memory. Long practice has given me a fair control of my vaso-motors, but my grip has never been sure when a letter or some incident brought suddenly to my mind the tragedy of the life of "Jack" Hewetson. As I write there comes the far-away vision of a young face, frank and open, with the grey-blue eyes that looked so true, and a voice to match, with a merry laugh—no wonder that everyone loved him! Three happy years he lived with us, growing into a strong, earnest worker, and contributing with Dr. Thayer an important monograph on malaria, and many minor papers. Frank Smith and Barker, who joined the staff about the same time, became his devoted friends. The controller, Mr. Winder Emery, at once fell under his spell, and it was touching to see the affection with which the stern old martinet regarded the younger man. In 1894 Dr. Hewetson went to Germany, and in Leipzig appeared the signs of pulmonary tuberculosis. He had had a pleurisy in Montreal, and the disease made rapid progress. He returned to California, where his father lived, and began to fight the long and losing battle which has just ended. Brave and cheerful, never repining, even in his broken life, much happiness—happiness that comes with a devoted wife and faithful friends. We who loved him in those early days have never recovered from the tragedy of the wreck of a career of such peculiar promise. W. O.

Dr. John Hewetson, the eldest son of the late James Hewetson, of Riverside, California, was born in Bruce County, Ontario, in 1867. He was educated in Canadian schools,

spending several years at Upper Canada College in Toronto. Entering the Medical Department of McGill University, Montreal, in 1887, he was given the degree of M. D., after the regular course of study, by that institution in 1891. During his undergraduate days he was a member of the Zeta Psi Fraternity, and was elected to the highest office in the local chapter.

In 1890 he was appointed assistant resident physician in the Johns Hopkins Hospital, and in 1892 became the first assistant to the resident physician. During his service on Professor Osler's staff, in addition to his routine work, he undertook special studies, including pathological courses in Professor Welch's laboratory, and analyses of the typhoid statistics of the hospital. With Dr. Thayer, who was then resident physician, he made special investigations on malaria; the results were published in the monograph by Thayer and Hewetson entitled "The Malarial Fevers of Baltimore."

The International Medical Congress was held in Rome in 1894; Dr. Hewetson went to Italy to attend the meeting as the delegate of the Johns Hopkins Hospital.

He began his European post-graduate studies in 1894, when he settled in Leipzig and took up work in the Anatomical Institute of Prof. Wilhelm His. After following the course in human embryology he became especially interested in the development of the human nervous system, and under Hans Held prepared several series of exquisite preparations of the medulla, pons and mid-brain of new-born babes, stained after Weigert's method. Stimulated by the lectures of His and Held, and also by the demonstrations of Paul Flechsig, it was his intention to make exact studies of the series he had prepared with the hope of throwing fresh light upon the development of the conduction paths in this portion of the central nervous system. His plans were suddenly interfered with by his discovery of tubercle bacilli in his own sputum in the summer of 1895, while actively engaged in laboratory work. He had suspected the possibility of the disease from some symptoms which had recently developed, especially as he had suffered from an attack of pleurisy in Montreal, and because he knew himself to be predisposed, since his mother and sister had suffered from pulmonary tuberculosis.

Interrupting his work in the anatomical laboratory he set out at once for the hills of Southern Bavaria, where he began his long fight against his malady in Partenkirchen-Garmisch. Later on he spent some time at Les Avants (above Montreux). Subsequently he made a voyage to Australia. In 1897, somewhat improved, he returned to Riverside, California, where he afterward lived, spending the summers in British Columbia, until his death in St. Joseph Hospital, Victoria, B. C., September 22 of this year. His death was doubtless hastened by the loss of his devoted wife in the preceding year.

The preparations on the nervous system which Dr. Hewetson prepared, though they could not be used by himself, were turned over to Professor Mall's laboratory in Baltimore, and served as the basis for a number of studies in that institute. The illustrations of transverse sections and horizontal sections of the medulla, pons and mid-brain in my book on "The Nervous System and its Constituent Neurones" were drawn by Louis Schmidt from these specimens, and the wax model made by Ziegler, of Freiburg, after the reconstruction of Dr. Florence Sabin, also had its origin in Hewetson's sections. A number of under-graduate and graduate students who have worked in the anatomical laboratory in Baltimore on the structure of the nervous system have had the opportunity of studying the original preparations.

Important as the medical work of Dr. Hewetson was, it was over-shadowed by the character and personality of the man, and by his peculiar power of inspiring respect, friendship and affection, as is well shown by the tribute paid to him by Professor Osler in this number of the BULLETIN.

LEWELLYS F. BARKER.

ELECTROCARDIOGRAPHY AND PHONOCARDIOGRAPHY.

A COLLECTIVE REVIEW.

By LEWELLYS F. BARKER, M. D.,

Professor of Medicine, Johns Hopkins University, and Physician-in-Chief, Johns Hopkins Hospital, Baltimore, Md.

The clinical study of diseases of the circulation has, during the past few years, made exceptional advances. In addition to improvements in the time-honored methods of inspection, palpation, percussion and auscultation, a number of new and important modes of investigating cardio-vascular conditions have been introduced, notably (1) the methods of simultaneous graphic registration of apex beat, arterial pulse and venous pulse; (2) the methods, palpatory, oscillatory, auscultatory, of registering maximal and minimal arterial pressures, and (3) the methods of determining the exact size and movements (a) of the several chambers of the heart and (b) of the great vessels by means of roentgen rays (fluoroscopy, roentgenography, orthodiagraphy).

Still more recently another method of investigating the heart, and one based upon an entirely different principle from any of those before mentioned, has been attracting the attention of physiologists and clinicians. I refer to the study of the differences in electric potential which occur in different parts of the heart muscle preceding and during their activity. These differences in electric potential can now, thanks to the invention of extremely delicate instruments for the purpose, be graphically registered as electrocardiograms. The whole

procedure of the study of the electrical changes in the heart is known as *electrocardiography*, and it is the present status of this subject which will be reviewed in this paper. In passing, I may mention, also, the methods of *phonocardiography*, which make an attempt at greater precision in the analysis of the sounds audible over the heart.

HISTORICAL NOTE.

The doctrine of animal electricity has had a chequered career. The fundamental discoveries of Galvani made more than one hundred years ago were at first most enthusiastically received, but they excited temporarily too many hopes which failed of immediate realization and like many other great discoveries Galvani's soon suffered from neglect. Except for the researches of Nobili and later of Matteucci electrophysiology remained almost a sterile field from Galvani's time until about the middle of the last century, when du Bois-Reymond took it up as a special study and revived occupation in it. Though his work and discoveries insured the permanency of electrophysiological doctrines, interest in the subject soon became over-extended and suffered an inevitable reaction even during the life-time of the distinguished leader of physiology in Berlin. These experiences of Galvani and of du Bois-Reymond, respectively, have put the medical world on its guard; it is solicitous lest it permit itself a third time to indulge in over-expectation and premature enthusiasm in connection with electrophysiological investigations. In a modest way, however, the studies of the electrical changes which occur in the body are proving to be helpful in the solution of several physiological and clinical problems; perhaps as fruitful and as promising as any are the researches which have been and are now being centered in the electromotive phenomena of the musculature of the heart.

I should like to point out at the very beginning that these electrical studies seem to have to do with the excitation of the heart muscle rather than with its contraction; excitability (or the bathmotropic function in the sense of Engelmann) is a phenomenon analytically separable from contractility (or the inotropic function), and the electromotive changes under consideration appear to be more intimately related to the former than to the latter; indeed we may regard electrocardiography as affording us an entirely novel method of approach to the study of cardiac function since, through it, we seem to have for the first time a *method of measuring and contrasting cardiac excitations*. The *chronotropic* (or timing), the *dromotropic* (or conducting), and the *inotropic* (or contracting) functions were all more or less accessible to investigation before; but now, we appear to have a way of examining also the *bathmotropic* (or excitation) function.

The tissues of the human body present certain electrical phenomena when at rest (so-called *resting current*); but still more interesting are the changes which occur at moments of excitation (origin of so-called *action current*). The principles involved are very clearly explained in Biedermann's *Elektrophysiologie* (1895) and in Samojloff's recent monograph (1909), on both of which I draw freely in the following description. The moment any point of an excitable tissue is stimulated it undergoes an electrical change, becoming electrically negative as regards other points of the excitable tissue not under stimulation. In other words the tissue at the moment of stimulation becomes converted into a galvanic element, the excited point becoming electronegative (or the negative pole of the element) while all the non-stimulated portions of the tissue taken together become electropositive (or the positive pole of the element). A good deal of confusion has arisen regarding the use of the terms electropositive and electronegative. In a galvanic element the zinc is called on the one hand electropositive because in the fluid of the element the current runs down from the zinc to the other metal, but on the other hand, the zinc is at the same time the negative pole of the element since the current through a wire connecting the two metals of the element passes from the other metal to the zinc. All confusion will be avoided if it be kept in mind that the stimulated point in the excitable tissue becomes negative in the sense in which the zinc is the negative pole of a galvanic element. This can be well illustrated by the simple diagram (Fig. 1) used by Samojloff. If in the excitable tissue *AB* the point *a* undergoes excitation

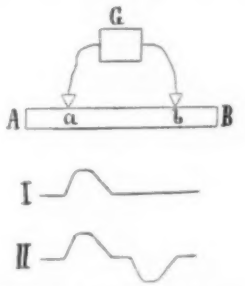

FIG. 1.—Scheme illustrating the action currents in an irritable structure (from Samojloff (A.), Elektrokardiogramme, Jena, 1909).

it will become electronegative in the sense above mentioned, and if two electrodes, connected with a galvanometer *G*, be applied at the points *a* and *b* a current will flow in the excitable tissue from the place of higher potential to that of lower potential, *i. e.*, from *a* to *b*, while in the outer part of the circuit the current will flow from *b* through the galvanometer to *a*. Now if the excitation be limited during the observation to the point *a* and vary only in its strength (starting from nothing, increasing to a maximum and then returning to nothing) an action-current will arise which, when plotted in a curve (with the intensity of the current as ordinates and the times as abscissæ), will take some such form as *I* in the figure. But the process is usually complicated by the fact that besides excitability the structure possesses the power of conductivity, in which event the excitation will gradually spread from *a* to the other points in *AB* and will ultimately reach the point *b*. The curve may then assume one of several different forms; if when *b* is reached *a* is again at rest the action-current would present two phases with opposite signs, say like that in *II* of the figure, which shows a diphasic cur-

rent in which a is first negative as regards b and later b is negative as regards a. Or, the excitation may reach b before a is at rest, and in that event the curve will represent the algebraic sum of the curve for the excitation process at a and the curve for the excitation process at b. The exact form of the curve will depend upon the duration and intensity of the excitations at a and b, on the velocity of conduction through the irritable structure and upon the distance between the electrodes.

We have begun by assuming a knowledge of the course of excitation in the system AB and have constructed a curve which a galvanometer thrown into the outer circuit would yield. By a reversal of the process one sees at once the application of the electrophysiological method. Assume that the excitation-process in the system AB is unknown; by experiment lead off the action-current by electrodes applied at the points a and b; a study of the galvanometric curve obtained will form the material from which inferences may be drawn regarding the excitation in the system AB. Thus if it were possible to lead off the current from the living heart of a man or an animal, the curve of the action-current obtained (or so-

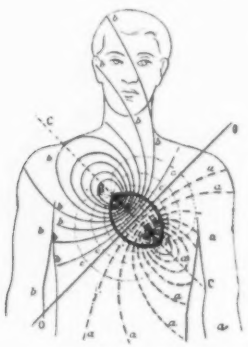

FIG. 2.—Distribution of cardiac electricity on the surface of the body (after Waller (A. D.), Phil. Trans. Roy. Soc., Lond. (B), 1889).

called electrocardiogram) would permit us to investigate the happenings in the heart muscle in an entirely new way.

As early as 1865 Koelliker and Müller had demonstrated the rhythmic current variations in the beating frog's heart by means of the rheoscope and had found two elevations in the same direction on the curve during the contraction of the ventricle. A great step forward was made in 1889 when A. D. Waller for the first time demonstrated the possibility of galvanometric registration of the action-currents emanating from the human heart. The idea occurred to him that, though the heart is not directly accessible to the electrodes, still it is practically accessible electrically since it is surrounded on all sides by masses which conduct the electric current. The action-currents in the heart thus affect the potential of the tissues of the whole body and by connecting electrodes with the moist skin it is possible to lead off the currents and to measure their strength by means of a galvanometer. Naturally the form of the curve will vary with the sites of derivation of the current; the curve when the current is led off from the two hands will be different from that led off from the right hand and right foot and both in turn from that led off from the left hand and the left foot. Waller's scheme of the distribution of the potential-differences in the body is shown in Fig. 2. It pictures the body as divided into two parts separated by an oblique plane, the part above and to the right taking on the electrical tension of the base of the heart and the part below and to the left acquiring the electrical tension of the apex of the heart. Though this scheme has had to undergo some modifications as a result of subsequent studies and is limited in that it pays attention to only two points in the heart muscle, one at the base and the other at the apex, still it suffices to illustrate the principle of the derivation of the action currents.

At the time of Waller's work the most sensitive apparatus available for measuring feeble electric currents was the capillary electrometer; a curve was obtained by photographing the movements of a mercury meniscus (Fig 3). The lag or inertia of mercury is, however, so great that the curve obtained had to be corrected by rather elaborate mathematical calculations in order that a true idea of the electrical variation could be gained. While Waller evolved the method of leading off the currents from the living heart and made as

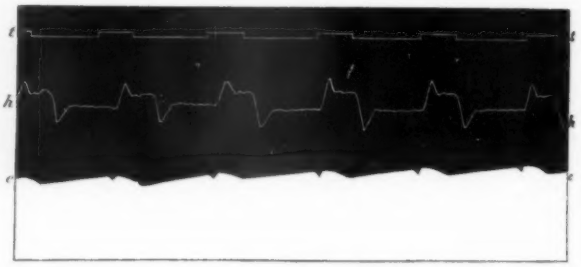

FIG. 3.—The action currents of the human heart (*ee*) recorded by the capillary electrometer registered simultaneously with the cardiogram (*hh*). The time marker gives the tracing *tt* (after A. D. Waller).

good electrocardiograms by photographic methods as could be made with the means at his disposal, he had no idea that any clinical application of electrocardiography would be made.[1]

[1] Writing even very recently (May, 1909), Waller admits this and, to my surprise, despite his admiration of the delicacy and accuracy of Einthoven's string galvanometer, still fails to see any or only a very slight clinical future for the procedure. He writes as follows:

"I do not, however, imagine, nor, I believe, does Einthoven, that the string galvanometer, however useful and even necessary it may be in the physiological laboratory, is likely to find any very extensive use in the hospital as affording means of physical diagnosis more searching than those in daily use. It can at most be of rare and occasional use to afford a concrete graphic record of some rare anomaly of cardiac action, as it has already in the hands of Einthoven, Lewis and others served to bring into clear evidence the extraordinary disorders of contraction of which the diseased heart is capable. But for all ordinary purposes of diagnosis the finger tips of the physician will hardly

By far the most important step in electrocardiography was made in 1903 when the Dutch physiologist Einthoven of Leyden devised his string galvanometer based upon the suggestions of Ader (Compt. rend. Acad. Par. 1877) regarding an instrument for use in international telegraphy. Einthoven's work resulted in an apparatus of extreme sensitiveness, utterly aperiodic, without lag and easily applicable to clinical and physiological research. In the assembling of the galvanometer and all its accessories the mechanician Edelmann of Munich has performed a useful service (*vide infra*).

Einthoven's String Galvanometer and Edelmann's Electrocardiographic Station.

The string galvanometer of Einthoven is truly an instrument to make one marvel. The device has simplified electrophysiological investigation to an extraordinary degree and has made the taking of electrocardiograms of the human heart, in hospital work at any rate, an easy and practical procedure.

Einthoven's studies with the capillary electrometer of Lippmann soon convinced him that though this instrument is aperiodic (that is, when started into movement by a current shows no oscillations of its own which could deform the curve), it does not possess the necessary quickness of response to a given strength of potential when sufficiently sensitive for very feeble currents or, if sufficiently responsive, becomes insufficiently sensitive. A wholly suitable galvanometer must, besides being entirely aperiodic, be almost without lag or inertia and must be sensitive to electric currents of minimal intensity.

All the desiderata have been realized by Einthoven in the construction of his string galvanometer. In most galvanometers the magnet is the movable part and the current to be measured passes through the stationary coils. In Einthoven's instrument an opposite arrangement has been made; the magnet is stationary and the current passes through a movable thread or string. This movable conductor of the current is extremely attenuated, being a thread of 0.001-0.003 mm. in thickness. Two kinds of threads are used—either one of quartz (coated with silver to make it conduct) or one of platinum. A very good platinum thread is one 85 mm. long with a diameter from two to four microns (*i. e.*, from one-third to one-half the diameter of a red corpuscle), so delicate that it can be seen clearly with the naked eye only when powerfully illuminated against a dark background. Such a thread is too light to be weighed even with extremely sensitive balances, though its weight has been calculated to be about 0.00262 or 0.00685 milligrams (Einthoven). Of course such threads are expensive; clinicians will probably work chiefly with platinum threads as they are quite sufficient for clinical work and are less fragile than the quartz threads; besides they do not lose their conducting power as the quartz thread may do from scaling off of its silver coating.

The ends of the thread are made stationary, so that the thread swings like the string of a musical instrument—hence the designation "string galvanometer." The relations of the string to the pole-shoes of the magnet are illustrated in Fig. 4. Since the magnet must be strong, it is customary to use an electromagnet, though some of the smaller instruments work very well with non-electric magnets. The string is suspended midway between the pole-shoes (*P*, *P*, in Fig. 4). It is a well-known physical

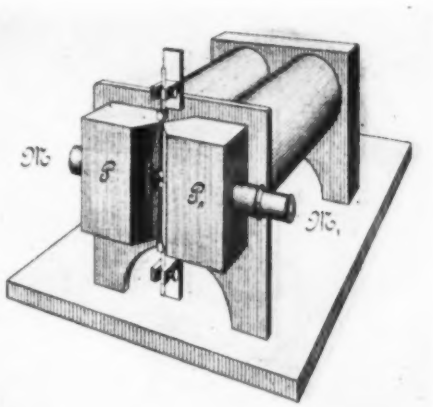

Fig. 4.—The string galvanometer devised by W. Einthoven (from Einthoven (W.), Le Télécardiogramme, Arch. Internat. de Phys., 1906-7, iv, 133).

fact that when an electric current is passed through a magnetic field it undergoes a deflection perpendicular to the lines of magnetic force which pass between the two poles of the magnet; thus when a current passes through the string of Einthoven's galvanometer the current is deflected *and with it the string*. The deflection will be to one or the other side according to the direction in which the current passes through the string; the stronger the current which passes through, the greater the deflection and *vice versa*. The thread of Einthoven's instrument is so delicate that it is suitable only for the measurement of very feeble currents which cause only slight oscillations of the string; a tyro working with the instrument may easily break the thread by permitting too great a deflection from the passage through the string of too strong a current. In order properly to value the oscillations which result from the passage through the galvanometer of the feeble action-currents of the heart a magnifying apparatus is essential. Einthoven perforates the nuclei and poles of the

be helped by an instrument as difficult to manage and to interpret as the string galvanometer."

This judgment has, I fear, been passed without sufficient consideration. Once an electrocardiographic station (of the type devised by Edelmann (*vide infra*) for applying Einthoven's string galvanometer) has been set up, one can more quickly, easily and certainly analyze a cardiac arhythmia by its use than by any other method. The technique, once acquired, is not difficult, and is far less irritating and baffling than that of making phlebograms and arteriograms in difficult cases. It will not, of course, supplant other clinical methods, but that it supplements them definitely and represents a real and permanent advance in the methodology of cardiac investigation no one who has studied any large number both of normal and of pathological cases with its aid can doubt.

magnet in the middle and inserts two microscope-tubes (M and M_1 of Fig. 4) in the openings. One of these is provided with an objective for focussing a strong electric light upon the string; the other is a projection microscopic, consisting of an objective (or of an objective and an ocular) which throws an enlarged image of the illuminated string upon the slit of the photographic apparatus, or upon a white ground on which the movements of the thread may be observed with the naked eye. Thanks to the attenuated nature of Einthoven's string, it is completely aperiodic, the damping by the air together with the electro-magnetic damping (the latter being directly dependent on the field-strength of the electro-magnet) being sufficient completely to prevent any oscillations proper to the string itself; one can be sure, therefore, that the deflection of the thread, on passing a current of definite intensity through, is due to this alone. Again, the fact that the deflections of the thread are really microscopic excursions explains how it is possible to get such an immediate deflection or "setting" of the thread for a current of given strength. Still further, the size of the waves in the curve can be varied not only by the degree of optical magnification of the image of the string, but also, and this is very important, by changing the tension of the string by means of a screw at one end of it; the tighter the string is stretched the smaller the excursions made by the thread and the shorter time it takes for the deflection or setting; and, *vice versa*, if the string be loosened a current of the same intensity will yield a wider excursion but it will be made more slowly. Obviously, therefore, in order that curves of comparable value may be obtained it is desirable to know the sensibility and setting-velocity of the instrument at the times the curves are made. Einthoven recommends for routine examinations of human hearts that the instrument and recording apparatus be adjusted so that in the curve obtained 1 mm. of abscissa corresponds to 0.1 second and 1 mm. ordinate to 10^{-4} volt, or in other words, 1 cm. of excursion of the string in the record represents 1 millivolt. The lag is so slight that the setting requires only 0.001 second. The sensibility with the finest quartz threads is such that 0.1 mm. $= 10^{-12}$ ampere (the photographic record of the excursion being a 1000-fold magnification). It is to be remembered that the thinner and shorter the string, the more sensitive it is (assuming strings of identical quality).

When the string is oscillating to the action-currents of the human heart, only the larger oscillations are discernible to the naked eye even in the magnified projected image. In order to make out the smaller excursions and to obtain curves as permanent records *photographic registration* is essential. Accordingly the magnified image of the string is projected by means of a powerful electric light upon a slit in a dark box which contains a moving photographic film or sensitive bromide paper. The slit opens and shuts when required by electric signal, and the movement of the film can be begun or stopped at will. Ordinarily a film half the length of an ordinary kodak film will suffice for one observation, but when extrasystoles occur but rarely or when for any other purpose observation of all the electrical results of the heart muscle over a considerable length of time is desired, much longer films may be employed. It is best to use a recording apparatus which will permit a photograph 75 meters in length to be taken without intermission. Smaller portions of this long film may be used and clipped off for development as desired.

Since the long axis of the slit in the box is placed horizontally and the string of the galvanometer makes excursions either to the right or to the left, the record on the film which moves vertically in front of the slit is in the form of a curve in which the excursions are up and down; the arrangement is such that when the action-current is due to electronegativity of the base (*i. e.*, is one in which the base of the heart corresponds to the negative pole of a galvanic element), the excursion on the film is in the upward direction, while when the action-current is one indicating that the apex of the heart is electronegative (*i. e.*, the apex corresponds to the negative pole of a galvanic element), the excursion as seen in the film is in the downward direction. When there is no action-current, or when multiple action-currents exactly neutralize one another, the string stands still in its middle position and a straight horizontal line is registered on the recording film.

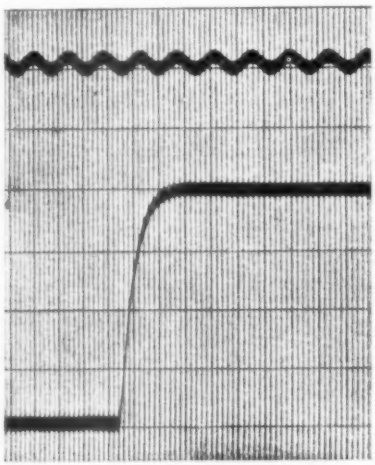

Fig. 5.—Curve showing sensibility of galvanometer. A current of 4 millivolts has produced a deflection which in the record amounts to 4 cm. The tuning-form vibrates 100 times per second (after Samojloff (A.), Elektrokardiogramme, Jena, 1909, p. 9).

A lever connected with a chronometer marking fifths or tenths of a second oscillates before one end of the slit, so that exact timing of the excursions in the curve is possible. One can also record on the same film a curve of the carotid pulse by placing before the slit a lever connected with a tambour and receiver; perhaps still better for this purpose is registration of the carotid pulse by means of a telephone and a second smaller galvanometer, the string of which is projected on the same slit. If desired, such a second galvanometer may be used in connection with a microphone, and an electrophonographic record of the heart sounds be made simultaneously with the electrocardiogram upon the film.

Where exact measurements of the ordinates and abscissæ

of the curve are desired the procedure is simplified by the application of a method introduced by Garten; while the photograph is being taken the light is intermittently interrupted by a spoked wheel set up in the path of the light rays; the picture then appears crossed by a series of vertical lines which run parallel to the slit and give a series of ordinates. If in addition a glass slide ruled with parallel lines running perpendicularly to the slit (*i. e.*, parallel to the abscissa of the electrocardiogram to be taken) be placed in front of the latter, the curve will appear plotted upon a network, making exact analyses very easy. In Fig. 5 I have introduced from Samojloff a curve illustrating the effect of the passage of a current of definite strength through the galvanometer arranged in this way. It is easy to see how promptly the excursion of the string from its zero position to its new equilibrium position occurs; one sees no trace of vibrations inherent in the string—the instrument is absolutely aperiodic. The time in this instance is marked by a curve due to a tuning-fork with 100 vibrations per second. Note how brief a time

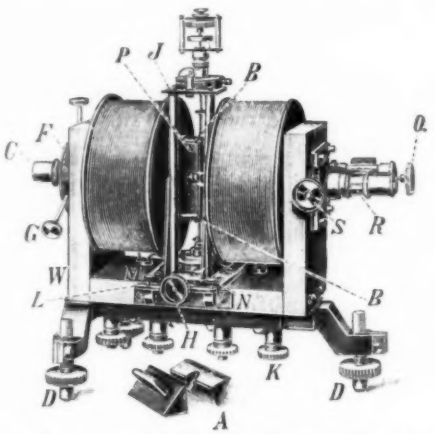

FIG. 6.—String galvanometer (large model) made by the mechanician Edelmann of Munich (from the pamphlet by M. Edelmann, Jr., Munich, 1908, p. 2).

was required for the excursion to become complete (between 0.01 and 0.02 second)—the "setting" was very prompt, showing how little lag or inertia there was to the string. As regards the sensitiveness in this particular instance Samojloff connected the quartz thread (the resistance of which amounted to 6700 ohms) with a portion of a rheochord whose ends showed a difference of potential of 4 millivolts. Since the excursion measures 4 cm. it will be seen that 1 mm. of excursion, in this instance, represents a tension, or electromotive force, of 10^{-4} volt and a current-intensity of 1.5×10^{-8} ampere.

Thanks to the mechanician Edelmann of Munich a complete electrocardiographic station may now be purchased by any hospital and be comparatively easily set up. The electrical "heart-station" consists of (1) the string galvanometer; (2) the electric light for illumination with its accessory apparatus; (3) the electrodes; (4) an apparatus for determining the resistance of the electrodes and of the body; (5) an apparatus for the determination of the sensibility of the galvanometer; (6) an apparatus for the compensation of the "zero current" or body-current, and (7) a photographic registering apparatus.

The electric arc-light should be focussed by means of a condenser, and a water bath is intercalated between the light and the galvanometer in order to absorb the heat rays.

For the details of the string galvanometer the description by M. Edelmann, Jr., in the fifth pamphlet issued by the firm of mechanicians in Munich should be consulted. Suffice it here to say that the original Einthoven construction has been very much simplified. The strength of the magnetic field remains about the same (approximately 20,000 units per cm.). A much shorter thread is used now; whereas the thread formerly employed was 140 mm. long, the Edelmann threads measure 87 mm. in length.

In Fig. 6 a view of the galvanometer is reproduced and in Fig. 7 the portion of it which carries the delicate thread. The thread itself extends between the points *h* and *h*. It can be tightened or loosened by the micrometer screw above.

The thread is accessible from all sides, a fact which makes centering much more easy than with former models.

It is unnecessary to use non-polarizable electrodes. The patient sits in a comfortable arm-chair. Three jars or pans made of zinc and filled with normal salt solution are the simple electrodes

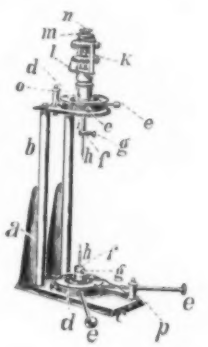

FIG. 7.—The string carrier of the galvanometer (from the pamphlet by M. Edelmann, Jr., of Munich, 1908, p. 3).

employed. These are connected up with wires. The patient places the right arm in one pan, the left arm in another and the left leg in the third. By means of a simple switch any two of these three electrodes may be connected with the galvanometer and one may thus lead off the current by any one of three methods of derivation (D_1, D_2 and D_3, *vide infra*).

RESISTANCE OF BODY AND ELECTRODES.

The apparatus for the determination of the resistance of the electrodes and of the body of the patient is an application of the principle of the Wheatstone bridge; the adjustment is made with the aid of an induction-coil and a telephone.

By the Wheatstone combination is meant an arrangement of conductors in such a way that a current passes through two branches, between which a transverse connection, the "bridge," exists. In Fig. 8 *E* represents the source of the current (battery); the current between the poles of the battery branches; the four "branches" are designated *a*, *b*, *c* and *d*; the transverse conductor, in which is intercalated a galvanometer *G*, constitutes the "bridge." The direction and intensity of the current which flows through this bridge depend upon the relation of the resistance in *a*, *b*, *c* and *d*. The current in the "bridge" ceases only when

the respective resistances stand to one another in the proportion

1. $R_a : R_b = R_c : R_d$.

Obviously if any three of the resistances are known the fourth one can be calculated; thus—

2. $R_a = R_b \times \frac{R_c}{R_d}$; or, $R_b = R_a \times \frac{R_d}{R_c}$.

For convenience, in place of c and d it is customary to use a so-called "slide-wire," namely a wire of high specific resistance along which a metal contact-clip may be slid. Since in this case c and d are wires of the same quality and diameter it is not necessary to know the values of R_c and R_d in ohms; it is sufficient to know merely the length of c and that of d along with the value of either R_b or R_a in order to determine the fourth resistance at once.

Since in electrocardiography we have to deal with electrolytes, it is desirable to use, not a direct current from a battery and an ordinary galvanometer, but rather the secondary current of a small induction-coil which is generated by an interrupted primary current from a battery. The Wheatstone bridge is thus supplied with an alternating current and the galvanometer is replaced by a delicate telephone. The arrangement is illustrated in Fig. 9.

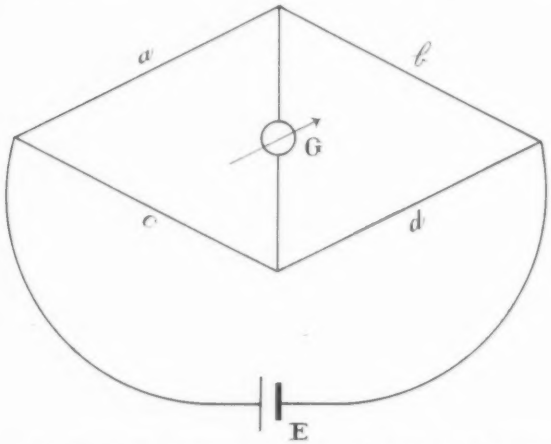

FIG. 8.—Diagram illustrating the principle of the Wheatstone bridge.

Here the source of the current is an induction-coil fed by battery and contact-breaker; the telephone is in the "bridge"; R_b is the resistance offered by the body and the electrodes; R_a is the amount of resistance introduced by an adjustable resistance-varier (rheostat); c is the length of wire to the left of the slide-contact and d the length of the wire to the right of it. Having a resistance of 1, 10 or 100 ohms in R_b, the slide-contact is passed along the wire until a minimal tone is audible in the telephone. Here—

3. Resistance in body and electrodes = Resistance in rheostat $\times \frac{\text{length of } d}{\text{length of } c}$.

The resistance of the body and the electrodes is usually somewhere in the neighborhood of 500 ohms. It is desirable to arrange R_a so that, in extinguishing the current in the bridge, c and d come to be of nearly equal length.

TESTING THE SENSIBILITY OF THE GALVANOMETER.

By the sensibility of a galvanometer is usually understood the strength of current which yields an excursion of one millimeter; thus a galvanometer with a sensibility of 1 milliampere is one in which an excursion of 1 mm. follows upon the passage through it of a current of the strength of 0.001 ampere. When the resistance of the galvanometer is known the so-called volt-sensibility can be calculated from the ampere-sensibility according to Ohm's law:

$$I = \frac{E}{R} .$$

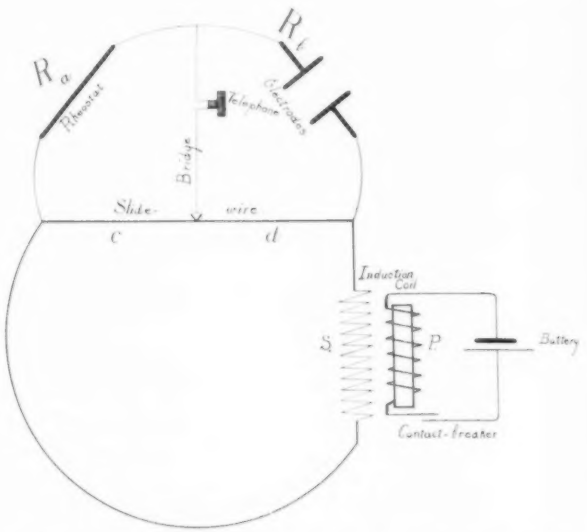

FIG. 9.—Illustration of slide-wire modification of arrangement for Wheatstone bridge.

I represents the intensity of the current in amperes; E the electromotive difference of potential in volts and R the resistance in ohms. Thus, obviously, $E = I \times R$.

If, for example, a galvanometer has the sensibility of 1 mm. =

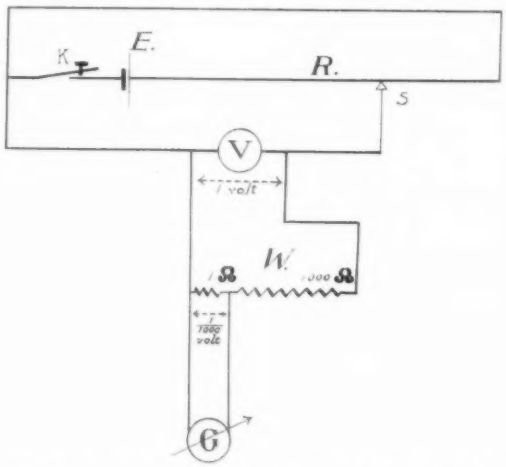

FIG. 10.—Diagram of simple arrangement for securing a current of 1 millivolt.

0.001 ampere and the resistance of the galvanometer is 100 ohms, then the volt-sensibility of the galvanometer is 1 mm. = 0.1 volt:

$$E = I \times R = 0.001 \times 100 = 0.1 \text{ volt.}$$

In the string galvanometer used in taking electrocardiograms it is usual to work with a volt-sensibility of 1 mm. = 10^{-4} = 0.0001 volt; in other words 1 cm. of excursion corresponds to a current of 1 millivolt.

In Edelmann's apparatus the thread is tightened or loosened until the passage of 1 millivolt (exactly measured) through the galvanometer causes an excursion of precisely 10 mm. In order to pass this current through the galvanometer it is desirable to have as a source of the current a so-called "standard cell" or "normal-element," that is, a battery between the poles of which a definite, known and fairly constant difference in potential exists. For this purpose Edelmann uses a Weston Standard Cell.[2]

The electromotive difference in potential yielded is about 1.0192 volts. Of this only 0.001 volt is required. This amount is obtained by arranging for a branching of the circuit and placing parallel to the standard cell a resistance of 101920 ohms; there is then a falling off in potential difference of 0.00001 volt for 1 ohm; if with a rheostat 10 ohms be stoppered off then (practically) 0.0001 volt is obtained. By stoppering off 100 ohms and making the tension of the thread such that an excursion of 10 mm. is obtained the instrument has the sensibility desired.

Since the Cadmium Standard Cell is expensive and unless carefully handled may be easily ruined, we have sought a simpler and less expensive method of sensitizing the galvanometer. At the suggestion of Dr. A. H. Pfund, of the Physics Department of the Johns Hopkins University, we have found an ordinary dry cell (with potential difference exceeding 1 volt), together with an inexpensive volt-meter, entirely satisfactory.

The arrangement of apparatus is shown in the following diagram (Fig. 10) where (E) is a dry cell, (K) a key and (R) a German silver wire. A shunt circuit is connected around the battery and a portion of the wire (R). This circuit contains a pocket voltmeter (V) and a sliding contact (S), the position of the latter being varied until the voltmeter reads exactly 1.0 volt. Next, a resistance box (W) is shunted around the terminals of the voltmeter. The potential difference existing at the terminals of (W) is 1 volt; hence, by stoppering off 1.001 ohms and by shunting the galvanometer (G) around this 1 ohm, a potential difference of 1/1000 (i. e. 1×10^{-3}) volt becomes effective at the terminals of the galvanometer. It only remains to tighten or loosen the thread until, upon depressing the key (K), a deflection of 10 mm. is produced. A deflection of 10 mm. corresponds to a potential difference of 1×10^{-3} volt; hence 1 mm. corresponds to 1×10^{-4} volt, which is the desired sensibility. We can recommend, as sufficiently accurate, this simple procedure, when a standard cell is not available. In Fig. 5 has been shown a curve obtained when a current of 4 millivolts is passed through the galvanometer properly sensitized; the deflection of the string is 4 cm. and the promptness with which the string assumes its new position is obvious when one notes the time-tracing above, where each wave represents 1/100 second.

[2] It differs from Latimer Clark's Standard Cell in that cadmium and cadmium sulphate are used instead of zinc and zinc sulphate, and is hence less susceptible to variations in temperature. The amalgam in it contains 10 to 18 gm. Cd. to 90 to 87 gm. Hg.

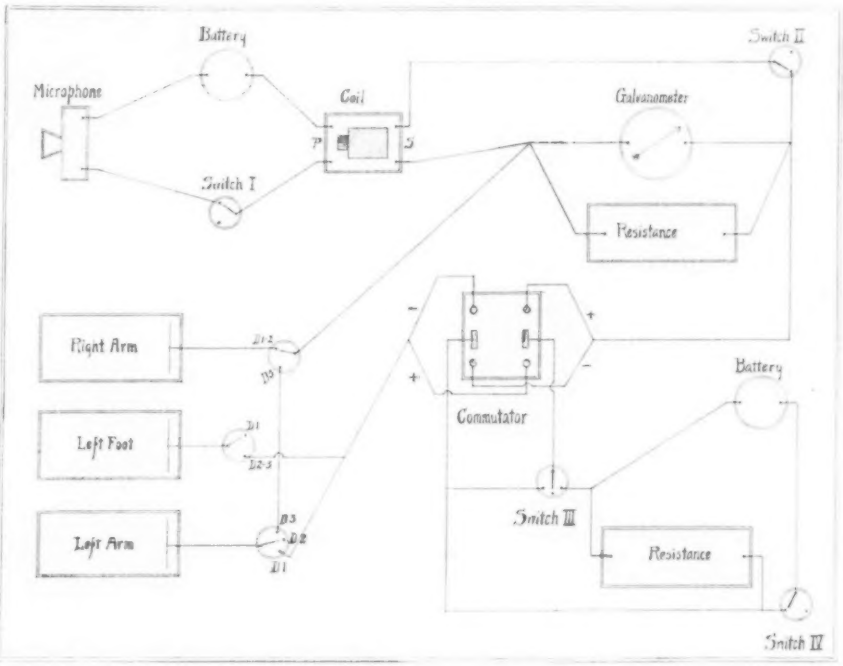

FIG. 11.—The wiring for inexpensive heart station.

COMPENSATION OF THE "ZERO-CURRENT."

The body of the patient and the electrodes yield a current which should be neutralized in order that the action-currents from the heart may be studied for themselves. With the aid of an "accumulator cell" (as compensation battery), rheostats, and slide-wire resistance, the compensation is effected so that the galvanometer stands at zero (except, of course, for the excursions due to action-currents). For the details of this procedure the reader is referred to Edelmann's pamphlet.

PHOTOGRAPHIC REGISTRATION OF THE OSCILLATIONS OF THE STRING.

With Edelmann's larger outfit a film 75 meters long is available and as much or as little of it as desired can be used at a single sitting. The film does not have to be changed until the whole 75 meters have been used up; the individual exposures or series of exposures, being numbered, are clipped off as they are made, for development. The film can be passed before the illuminated slit at any one of several different speeds.

SMALLER INSTRUMENTS AND LESS EXPENSIVE ELECTROCARDIOGRAPHIC STATIONS.

We began our work in electrocardiography in the medical clinic here last year. On account of the cost, it seemed wise to make a

start with the smaller model of the string galvanometer made by Edelmann (Kleines Permanent-Magnet Saiten-Galvanometer), and to make the wiring so that a microphone could be attached to the same galvanometer for cardio-acoustic work. In the accompanying diagram (Fig. 11), prepared by Dr. Bond, it will be seen how the connections were made.

The patient places left arm, left foot and right arm in the three electrodes represented, which consist of zinc pans filled with normal salt solution (8 grams to liter). From each of these wires are conducted to the three switches, by means of which any two of the electrodes can be connected to the main circuit. This gives the various derivations; D_1 right arm and left arm; D_2 right arm and left foot; D_3 left arm and left foot.

In the wiring of these care should be taken that in arranging for the different derivations, the direction of the current is not changed. The wire from the left foot should always go into the same main wire and in D_3 the left arm electrode should occupy the same position in the circuit as the right arm does in D_2; otherwise an inverted electrocardiogram will be obtained due to this wiring defect.

From these switches the two main wires lead to the galvanometer, one going directly, the other passing through the commutator. The movements of the commutator do not in any way change the direction of the current generated by the body. The commutator serves the purpose of connecting in and sending in either direction around the main circuit a current from the battery reduced to sufficient strength by the resistance coil. This is sent in the opposite direction to the body current and serves to neutralize the primary body potential ("compensation of the zero-current"). In some instances this factor can be disregarded so that Switch III is for the purpose of completing the main circuit, either including or excluding the battery circuit. A note should be made here that in the latter condition Switch IV should be opened to save the battery from short circuiting through the resistance coil.

FIG. 12.—View of inexpensive heart station in the medical clinic at the Johns Hopkins Hospital.

On a shunt circuit with the galvanometer is a resistance coil; the greater the resistance the stronger is the current passing through the galvanometer.

The wiring of the microphone is simple. It is connected with a dry battery in a circuit with the primary of an induction coil. Wires from the secondary lead to the junction points of the wires from the galvanometer and resistance coil. The constant battery current passing through the primary induces no current in the secondary. Changes though in the strength of this primary current as the result of sound vibrations on the microphone set up induced currents in the secondary and these are recorded by the galvanometer. Switch I opens and closes the primary circuit, while Switch II serves the same purpose in the secondary.

In Fig. 12 the general appearance of such a small station is shown. In Fig. 13 is another view from behind the small photographic recording apparatus. An enlarged view of the table on which the galvanometer stands is shown in Fig. 14.

FIG. 13.—Another view of the same heart station.

Tolerably satisfactory electrocardiograms can be obtained with this simple and inexpensive outfit, as will be seen by the records published in the paper read before the Association of American Physicians in Washington, last May,[3] and in the paper by the same authors read before the American Medical Association at St. Louis in June, 1910. For more detailed work, however, the more expensive instrument is desirable. We are now installing a larger and more complete heart station, outfitted with Edelmann's "Grosses Elektromagnet-Saiten-Galvanometer"; this is the one to be recommended for hospital use.

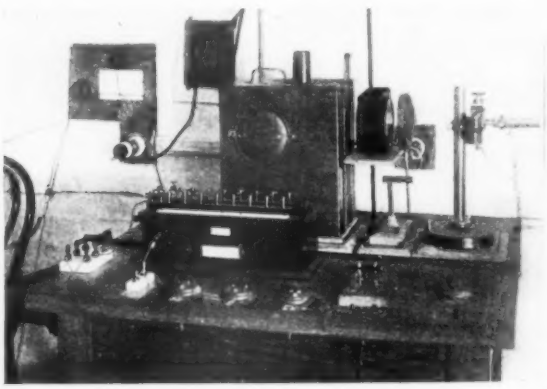

FIG. 14.—Enlarged view of galvanometric table of small station.

THE TYPICAL ELECTROCARDIOGRAM.

In healthy people an electrocardiogram obtained by leading off the current through the two hands under the conditions outlined above assumes, in the majority of instances, the form

[3] Barker (L. F.), Hirschfelder (A. D.), and Bond (G. S.): Personal experience in electrocardiographic work with the use of the Edelmann string galvanometer (smaller model).

shown in Fig. 15. The term "typical" or "schematic" is used instead of "normal," since several slight deviations from the type shown occur in people with normal hearts. The curve for each heart period presents constantly three principal excursions or waves upward (elevations) indicating a negativity of the base of the heart as regards the apex at three different times in a single cardiac revolution. These three elevations have been designated by Einthoven as *P*, *R*, and *T*. The curve presents also, in many instances, two slight excursions or waves downward (depressions), indicating a negativity of the apex of the heart as regards the base at two different times in each cardiac revolution. These two depressions, though less constantly present than the three elevations, have been designated by Einthoven as *Q* and *S*.

The small elevation *P* corresponds in time to the excitation of the two atria, while *R* and *T*, as well as *Q* and *S*, all belong to the time of excitation of the ventricular muscle.[1] The ventricular portion of the curve is conveniently divisible into two parts: (1) that formed by *Q*, *R* and *S*—*R*, by far the greatest of all five excursions, being sometimes designated the *initial ventricular variation;* and (2) that formed by *T* (which

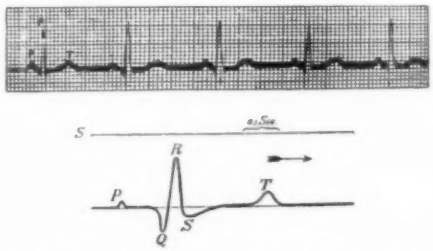

FIG. 15.—Normal electrocardiogram obtained by photographing the movements of a sensitive galvanometer. The upper figure shows the photographed curve, while the lower one is a diagram constructed from the photograph to make clearer the electrical changes in a single cardiac cycle. To obtain this record the electrodes were connected with the right and left hands. Waves with the apex upward indicate that the base of the heart (or the right ventricle) is negative to the apex (or left ventricle). Waves with the apex downward have the opposite significance. Wave *P* is due to the contraction of atrium. Waves *Q*, *R*, *S* and *T* occur during the systole of the ventricle. The curve seems to show that the contraction in the ventricles begins first toward the apex (or in the left ventricle), since the negativity first appears toward that side (wave *Q*). (Einthoven.)

is higher than *P* but lower and slower than *R*)—sometimes called the *after-variation* or *final variation of the ventricle.* The distance between *P* and *Q* (or *R*) represents the time required for the spread of the excitation from the atria to the ventricles and therefore is a good measure of the "A_s—V_s interval" of excitation.

A different terminology for the various excursions or waves of the curve has been suggested by Nicolai (Fig. 16). He pays especial attention to the three elevations which Einthoven calls *P*, *R* and *T*, but prefers to designate them *A*, *I* and *F*, since *A* is the expression of atrial excitation, and *I* and *F* the *initial* and *final* ventricular oscillations respectively. To the less constant *Q* and *S* he applies the terms *Ia* and *Ip* (anterior or posterior to the initial variation), and to similar slight depressions occasionally met with before and after *T* he gives the labels *Fa* and *Fp*. When *R* is doubled, a rare occurrence, he makes the second excursion I_2. The horizontal stretch between *P* and *R* he designates *h* to indicate that the excitation is at that time passing over the His bundle. The stretch from *R* to *T* he calls *t* for reasons to be mentioned later, while the stretch between *T* and the *R* of the next cardiac revolution is labelled *p* to indicate the pause in the heart's activities. I am sorry that this change in terminology has been suggested, especially as some of the ideas upon which Nicolai's lettering are based are still in dispute. It seems to me better not only on account of their priority but also on account of their freedom from explanatory significance to retain the letters used by Einthoven as termini. It cannot help but be confusing if some workers describe their curves in Nicolai's terminology, extremely interesting and important as his work is, while others use Einthoven's. For the present

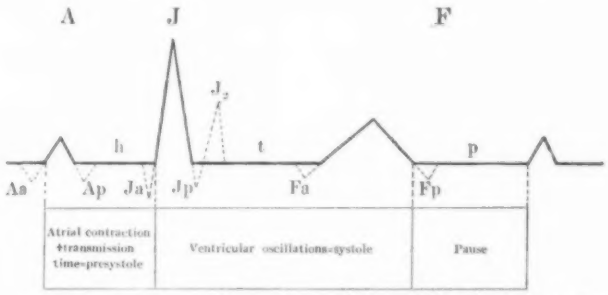

FIG. 16.—Analysis of electrocardiogram according to Nicolai (from Nicolai's article in Nagel's Handb. der Phys. des Menschen, 1909, I, 825).

at any rate I hope that workers in this country will follow Einthoven's lettering of the curves.

THE EFFECT ON THE ELECTROCARDIOGRAM OF ALTERING THE SITES WHENCE THE CURRENTS ARE LED OFF. VARIOUS LEADS OR METHODS OF DERIVATION.

The typical curve shown above was obtained by leading off the current from the two hands. It is not a matter of indifference what parts of the body are chosen for the derivation of the current; indeed there are very characteristic features of the curves from any given individual for different derivation-sites. The following three principal derivation-sites have been used and recommended by Einthoven and may be regarded as standard methods of derivation in making curves from the human heart:

Lead or Derivation I, right upper extremity and left upper extremity (Fig. 17).

Lead or Derivation II, right upper extremity and left lower extremity.

Lead or Derivation III, left upper extremity and left lower extremity (Fig. 18).

[1] Hoffmann calls attention to the resemblance of the ventricular portion of the electrocardiogram to the negative variations obtained by Judin from gastrocnemius of the frog.

The different curves obtained by varying the derivation make it imperative that in published curves explicit statements be made as to the methods of derivation resorted to in their production. Moreover, experience has already demonstrated the desirability of systematically making three electrocardiograms from each individual studied, one by each of the three modes of derivation mentioned. Important information may sometimes be gained from one of these which is wholly lacking in the others. I realize that this complicates the procedure somewhat for clinical use, but the advantages are so great that I cannot understand the indifference of Nicolai and Simons regarding the matter, still less the outspoken opposition of Strubell to the use of any derivation-site other than D_1. Strubell's argument is that physicians will be so confused by the use of three different sets of curves from the three derivation-sites that they will be disinclined to consider electrocardiography at all. It seems to me that any physician who will take the trouble to understand the mechanism of the string galvanometer at all and give the matter study enough to make himself familiar with an electrogram taken by D_1 will scarcely turn back if he is told that very distinct advantages are to be gained by the consideration also of the forms of electrograms obtainable by D_2 and D_3. Samojloff puts it well when he says, "One must test the heart for its electrical expression by examining it at different points. Just as one looks at an object from all sides in order better to understand its form, so one must try to ascertain the distribution of electric potential in the heart by successively altering the sites whence we derive the action-current."

FIG. 17.

FIG. 18.

FIG. 17.—Leading off current from the two arms, Derivation I (after Einthoven (W.), Le Télécardiogramme, Arch. Internat. de Phys., 1906-7, IV, 144, Fig. 14).

FIG. 18.—Leading off the current from the left arm and the left leg, Derivation III (after Einthoven (W.), Le Télécardiogramme, Arch. Internat. de Phys., 1906-7, IV, 144, Fig. 15). *a*, Carotid pulse and electrocardiogram, D_1; *b*, Carotid pulse and electrocardiogram, D_2; *c*, Carotid pulse and electrocardiogram, D_3.

In Fig. 19 are given three electrocardiograms taken by Einthoven from one and the same individual, with use of the three chief methods of leading off the current. It will be observed that the three main elevations P, R and T are recognizable in all the curves but that the appearance of these waves, their height and direction are somewhat different. A further feature, probably very important, is the discrepancy in the times at which the various waves occur with the three methods of derivation; the waves in the curves do not occur in identical phases of the cardiac revolution; that the dimensions of the three curves are definitely related to one another, however, is shown by the fact that the curve obtained by D_2 is approximately the algebraic sum of the curves obtained by D_1 and D_3. This may be expressed as the formula,

$$D_2 = D_1 + D_3.$$

If one examines a series of such curves he will be struck by the fact that this rule holds fairly well for the individual waves; thus for the wave R—

$$R_3 = R_2 - R_1,$$

and since T_1 is often as large or larger than T_2, we find that T_3 may be absent or even a depression instead of an elevation. In a rough way, therefore, given the curves by two of these methods of derivation, the third can be reconstructed from them. Not that such reconstructions are especially neces-

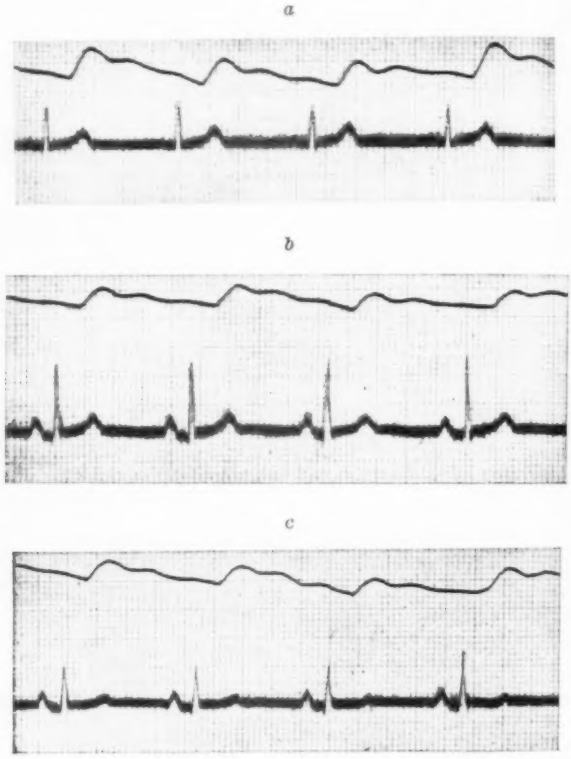

FIG. 19.—Comparison of the forms of electrocardiographic curves obtained by the three different methods of derivation taken from the patient *Ei* (after Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, 554, Figs. 16, 17, 18).

sary as a control of accuracy of the recording method, for the method of registration is now more accurate than any third curve reconstruction from the other two could be.

Hoffmann has recommended two other derivations for human beings. In one of these, which he calls derivation IV, he leads off the currents from the right arm and from the left parasternal line three fingers' breadth above the rib margins. In the other, which he designates derivation V, the currents are led off from the right arm and from the angle of the scapula in the back. It seems scarcely probable that derivations other than I, II and III will be necessary for routine clinical work.

The exact form of the curve in each of the several derivations depends largely upon the position of the heart. Waves which are small or absent in a curve obtained by one derivation may be well marked in a curve obtained by another derivation. In contrast with the asynchronism of the waves of typical electrocardiograms in the three derivations is the synchronism of the waves of the atypical electrocardiograms yielded by all three derivations in ventricular extrasystoles (*vide infra*). Observations on human beings and on dogs show that, as a rule, curves taken by derivation II yield the highest waves. A striking feature of the curves taken from patients with hypertrophy of the right or left ventricle is the large potential differences revealed by D_3.

Combined Electrocardiograms and the Comparison of the Electrocardiograms of Two Individuals with One Another.

As has been pointed out above, there may be slight deviations in health from the "typical" or "schematic" electrocardiogram described. The curve yielded by a single individual is, however, peculiarly constant if taken always under the same conditions. Electrocardiograms recorded over a period of one and a half years in the same individual have proven to be very similar to one another (Samojloff). As far as the instrumental side of the record is concerned, it is easier to realize identical conditions of registrations with the string galvanometer than with a sphygmograph.

In order to compare the curve yielded by two individuals at the same moment and with the same apparatus, various observers (Waller, Samojloff) have led off the currents from two people at once (*combined electrocardiograms*). This can be done in two ways, either by having one person with his right hand grasp the left hand of the second individual, the other two hands being immersed in the fluid of the electrodes, the two individuals facing the same way; or by having the two persons stand opposite one another, each facing in a different direction, their two right hands being placed in the fluid of the one electrode and their two left hands in the fluid of the other electrode. To use terms employed in describing the union of electric batteries the former arrangement may be called the *series method* and the latter arrangement the *parallel method.*

In Fig. 20 I have reproduced a curve taken by the series method by Samojloff and in Fig. 21 one taken by the parallel method by the same observer. It will be noted that the waves from the two hearts by the first method have the same direction, while in the second method they have an opposite direction on the film. In the portions of the records shown the waves due to the two hearts are easily recognizable. In the long original curves there are parts where the waves overlap or interfere with one another in such a way as to make recognition of the individual electrocardiograms difficult or impossible. Those who have taken combined electrocardiograms point out that the principal difference in the curves compared

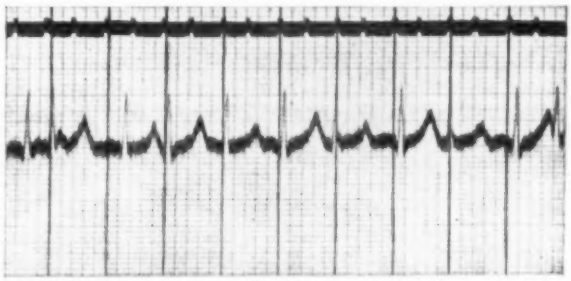

FIG. 20.—Combined electrocardiogram of two human hearts; arrangement in series. 1 cm. ordinate corresponds to 1 millivolt. Time markings 0.25 sec. Magnification 460 (after Samojloff (A.), Elektrokardiogramme, Jena, 1909, p. 26, Fig. 13).

lies in the height of the wave T, whereas the waves P and R are more nearly equal. It is interesting that the curves permit not only the decision that two hearts are beating but also a conclusion regarding the reciprocal orientation of the individuals under observation.

An ingenious application of the combined electrocardiogram has been made by Cremer of Munich. This physiologist recorded the curve (by a special method of derivation) from

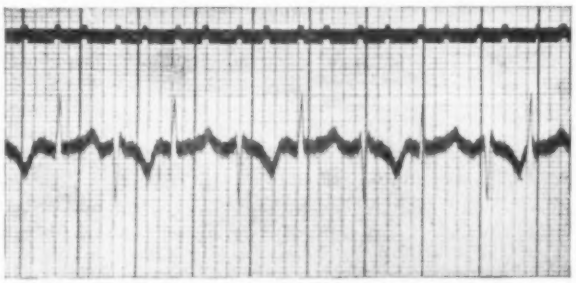

FIG. 21.—Combined electrocardiogram of two human hearts; arrangement in parallel. 1 millivolt corresponds to 1 cm. ordinate. Time marker 0.25 sec. Magnification 460 (after Samojloff (A.), Elektrokardiogramme, Jena, 1909, p. 27, Fig. 14).

a pregnant woman and was able to distinguish the waves due to the fœtal heart from those due to the mother's heart (Fig. 22). The possibility of confirming clinical obstetrical diagnoses and even of making positive diagnoses in otherwise doubtful cases by the aid of the string galvanometer is obvious. It seems probable that twin and multiple pregnancies may be easily diagnosed in this way; further, it is believed that with the aid of several derivations it may be possible to come to a

decision as to the reciprocal positions of the twins in the mother's body.

An effort has been made to regard the typical electrocardiogram taken from a healthy person as the combined electrocardiogram of the right and left sides of the heart. Kraus and Nicolai have gone farthest in this direction and base their opinions chiefly upon curves obtained when there is a lack of synchronism between the activities of the right side and the left side of the heart. Whether their conception is a correct

FIG. 22.—Electrocardiographic curve taken from pregnant woman, showing beats both of maternal and of fœtal heart (after Cremer (M.), Münch. med. Wchnschr., 1906, I, 813, Fig. 24).

one or not, further experience must determine. The relation to the clinical conception of hemisystole is obvious and Kraus and Nicolai maintain that such a clinical hemisystole is a reality.

THE TELECARDIOGRAM.

For several reasons it is often desirable to take tracings from patients who may be a considerable distance from the electrocardiographic station. In the first place many cardiac patients are too ill to be removed from a hospital ward to the heart station. Again in many instances an electrocardiographic apparatus will be set up in a physiological laboratory when one is not available in a hospital in the same town. To meet these requirements wires may be laid connecting various wards of the hospital with the heart station which is situated either in the hospital itself or in a physiological laboratory in the same town. Einthoven in Leyden laid wires between the Leyden Hospital and his laboratory, a distance of more than a mile, and took tracings in his laboratory from patients in the hospital wards. The main difficulty lies in the prevention of induced currents en route, but that such *telecardiograms* are feasible has been fully demonstrated.

A COMPARISON OF THE ELECTROCARDIOGRAM OF CERTAIN ANIMALS WITH THAT OBTAINED FROM MAN.

Physiologists naturally worked largely with animals, though the early studies were made with the aid of the capillary electrometer. For the more important observations we have to thank Waller, Gotch, Gaskell, Einthoven and Buchanan.

In recording electrocardiograms from animals, certain special methods have to be employed. The animal must be kept quiet, and for this purpose anæsthesia may be necessary. Electrodes of special type are used and one of the best methods of derivation is to lead the currents off from the œsophagus and from the anus. The sensitivity and speed of setting of the galvanometer have to be adapted to the particular animal under observation.

In Fig. 23 is reproduced the electrocardiogram taken from a dog; good curves from the frog are given in Samojloff's article in Engelmann's *Archiv*, 1906, *Suppl. Bd.* It is a very remarkable fact and very important for our understanding of the animal electrocardiogram that the frog's heart, which has only one ventricle, yields practically the same form of electrocardiogram as that given by a mammal. The similarity of the electrocardiogram yielded by the dog to that given by man is still more striking. These facts are of great importance for experimental physiology, for obviously, since the electrocardiograms of healthy animals are very similar to those of normal man, experimental modification of the electrocardiogram in dogs may be undertaken confidently, with the expectation that they will throw light upon pathological curves in human beings (*vide infra*).

One interesting application of the electrocardiogram has been the determination of the frequency of the heart beat and the form of the electrocardiogram in birds. Buchanan[1] has ascertained the frequency of the heart beat in a gold-finch, two green-finches, four sparrows, three pigeons and three hens. James Mackenzie had previously ascertained the frequency in a hen to be about 270 per minute. It turns out that the gold-finch's heart beats between 900 and 925 times per minute, the green-finch's heart between 700 and 848 times per

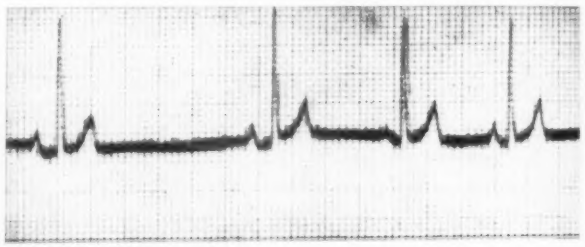

FIG. 23.—Electrocardiogram of dog's heart; D_2. Abscissa 1 mm. = 0.04 sec.; ordinate 1 mm. = 10^{-4} volt (after Einthoven (W.), Weiteres über das Elektrokardiogram, Pflüger's Arch., 1908, CXXII, 528, Fig. 3).

minute, the sparrow's heart between 745 and 850 times per minute, the pigeon's heart between 141 and 225 times per minute, the hen's heart between 304 and 345 times per minute.

ON CERTAIN EXTERNAL INFLUENCES WHICH MAY MODIFY THE FORM OF THE ELECTROGRAMS.

In a preceding paragraph the modifications of the electrocardiogram dependent upon the mode of derivation of the currents were referred to. It is necessary to understand also the effect of certain extra-cardial influences which may have an effect upon the form of the curve in order that modifications due to these shall not be regarded as evidences of change in the heart muscle.

Aside from the sensibility and setting of the galvanometer, polarization of the electrodes, shaking of the galvanometer, the following are the principal points to be attended to. The patient should sit in a comfortable chair with all his

[1] Buchanan (F.), The frequency of the heart beat and the form of the electrocardiogram in birds. J. of Physiol., Camb., XXXVIII, 1909, 62-66.

muscles relaxed since muscular tensions and contractions may modify the curve. Einthoven insists upon the patient sitting in a room separate from that in which the galvanometer is located, the two rooms being connected by wires. In hospitals the various wards may be connected by wiring with the heart stations. In Einthoven's laboratory in Leyden, the galvanometer records the currents of hearts of patients in the hospital a mile and a half away (*telecardiograms*).

The patient should breathe quietly. Respiration appears to affect the curve sometimes and not at other times. According to Einthoven the system of waves *Q, R* and *S* is depressed in deep inspiration. Sometimes only the wave *R* is diminished. These changes do not appear to be due to contraction of the respiratory muscles themselves, nor does the change in the position of the heart through the fall of the

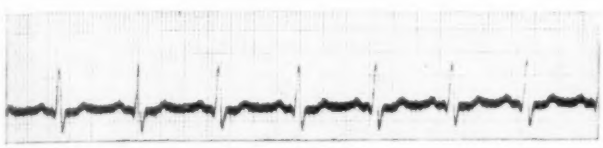

FIG. 24.—Electrocardiogram taken from a patient with Cheyne-Stokes breathing during a period of marked dyspnœa; D_1 (after Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, Taf. XII, Fig. 8. Only a portion of the original figure is reproduced).

diaphragm or the expansion of the thorax seem sufficient to explain the effect since only *Q, R* and *S* are affected while *P* and *T* are not. Nor would it seem probable that a modified contraction due to the action of the vagi or the accelerator nerves is responsible, for the changes occur without phase change precisely at the moment of deepest inspiration, and this would hint at some mechanical connection between the breathing movements and the electrical effects rather than a circuitous effect by way of the central nervous system. This

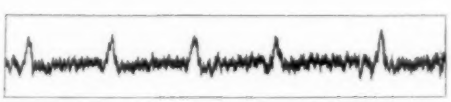

FIG. 25.—So-called splintering of the curve in myocardial disease (after Kraus and Nicolai).

idea is supported by Einthoven's observations—and it is to Einthoven especially that we are indebted for our knowledge concerning respiratory influences upon the electrocardiographic curve—of dyspnœa and Cheyne-Stokes breathing. In Fig. 24 I have reproduced his curve taken during violent dyspnœa; the other curve taken during apnœa can, he asserts, be scarcely distinguished from this one. They are so nearly identical that one can probably exclude the effect of the dyspnœa itself. Einthoven believes that the respiratory influences he has noted depend upon negative interpleural pressure, which is stronger on inspiration and could exert a definite influence upon the circulation. This influence would affect the right heart more than the left and this he thinks is the reason why the *Q, R, S* system is more modified than *T*.

Tremor of the hands of a patient will modify the curve and will sometimes give it a splintered appearance. It is not unlikely that the splintering of the curve described by Kraus and Nicolai (Fig. 25) in myocardial disease was due to tremor of the hands of the patient. The "splintering" is rather too fine to be accounted for by atrial fibrillation. Strubell has shown the effects of tremor on the curve in the hands of masseurs, gardeners and others. In old people and in weak individuals the effects of tremor should be noted. In the curves which we have taken in the Johns Hopkins Hospital from patients suffering from exophthalmic goitre the fine tremor does not seem to have caused much deformity of the curve. It would be interesting to take up systematically the study of different tremors (Graves's disease, Parkinson's disease, etc.).

A remarkable deformity of the curve is that which is produced by induction from alternating electric currents in the neighborhood of the instrument. The galvanometer is extremely sensitive to induction effects, especially those coming from the alternating current. Rothberger has pointed out that many of the curves published by Kahn (Pflüger's Arch., Bd. 126) show exactly one hundred oscillations per second.

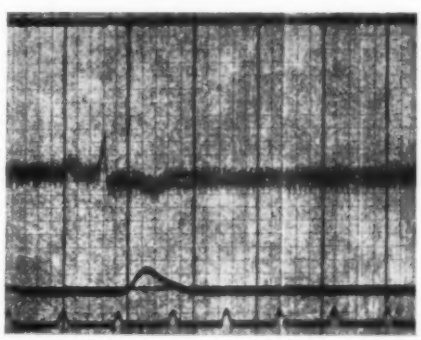

FIG. 26.—Regular tremor of the string due in all probability to induction from alternating current (after Kahn (R. H.), Pflüger's Arch., 1909, CXXVI, Taf. IX, Fig. 7. Only a part of the original figure is reproduced).

Kahn thought that these were due to jars of the instrument, but it seems likely that they were induction effects from an alternating current (Fig. 26).

Another very interesting factor which influences the form of the curve is the position of the heart itself in the thorax. This has been studied by Hoffmann and by Einthoven. Hoffmann showed that displacement of the apex of the cat's heart to the right distinctly affected the form of the curve and he has made observations on human hearts dislocated by pleural effusion and by blowing up the stomach. Strubell suggests that observations be made on patients when the stomach is empty on account of the influence of displacement.

Einthoven and Lint believe that the exact position of the heart in the thorax can often be determined by electrocardiographic examination with the three methods of derivation. They maintain that the height of the waves alone will show whether the heart axis is directed more from behind forward in one individual than in another.

A careful study of the relation of the electrocardiogram to the configuration of the thorax and the position of the heart (with orthodiagraphic control) has recently been made by H. Grau.

Clinical Observations in Human Beings.

Though the method is very new, it has already been introduced into the clinic by Einthoven, Kraus and Nicolai, Strubell, Hering and Kahn, Rothberger, Hoffmann, Lewis and others. In this country electrocardiographic outfits are being set up in the clinics of several of our larger cities. We have mentioned the heart-station at the Johns Hopkins Hospital; an excellent installation of the largest model and of the best photographic registration-apparatus has been made by Dr. Walter James at the Presbyterian Hospital in New York. He was able to demonstrate excellent curves at the association of American Physicians in Washington last May. In this article I shall refer almost entirely to European observers, reserving most of the curves made in our own clinic in Baltimore during this past year for the articles to be published in collaboration with Dr. Hirschfelder and Dr. Bond.

Among other clinical conditions which have been investigated may be mentioned: (1) the hypertrophy of the atria in mitral stenosis; (2) hypertrophy of the right ventricle in mitral stenosis; (3) hypertrophy of the left ventricle, especially in aortic insufficiency; (4) ventricular extrasystoles; (5) the tachycardia of exophthalmic goitre; (6) heart-block cases; (7) congenital heart disease; (8) atrial paralysis and pulsus irregularis perpetuus with atrial fibrillation; (9) the hearts of neurasthenic patients; (10) the hearts of infants; (11) paroxysmal tachycardias; (12) gallop-rhythms.

Hypertrophy of the Atria in Mitral Stenosis.

The atria (or auricles) are the chambers of the heart least accessible to physical examination. Our knowledge hitherto regarding the activity of the right atrium has depended chiefly

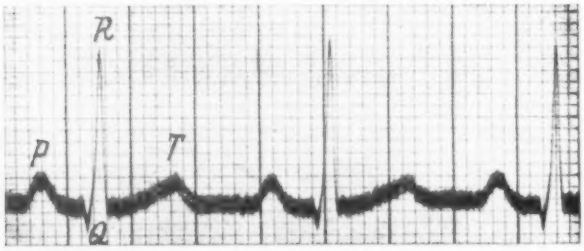

Fig. 27.—Electrocardiogram from a case of mitral stenosis. Note the exaggeration of the *P*-wave. I millivolt = 1 cm. ordinate, while 1 cm. of abscissa = 0.2 sec.; D_2 (after Samojloff (A.), Elektrokardiogramme, Jena, 1909, p. 29, Fig. 15).

upon observations of the venous pulse, while in rare instances observations upon the activity of the left atrium have been made by means of the œsophageal cardiogram (Minkowski). The electrical examination of the atria is made with the greatest ease and there can be no doubt that the *P*-wave of the electrocardiogram is synchronous with atrial excitation. In Fig. 27 is reproduced the curve taken from a case of mitral stenosis. The marked accentuation of the *P*-wave is obvious. It is fully as high as the *T* wave of the ventricular portion of the curve, which is never the case under normal conditions. Similar observations upon the high *P*-wave in mitral stenosis were made earlier by Einthoven.

Hypertrophy of the Right Ventricle.

In hypertrophy of the right heart R_1 may be negative and R_3 may be markedly positive (Fig. 28). An interesting case

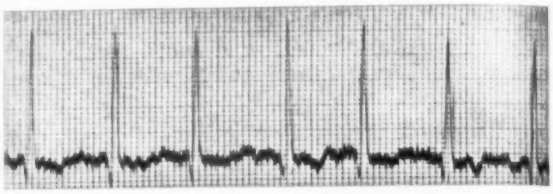

Fig. 28.—Electrocardiogram from case of mitral insufficiency with hypertrophy of the right ventricle; D_3 (after Einthoven (W.), Le Télécardiogramme, Arch. Internat. de Phys., 1906-7, IV, 145, Fig. 17).

of hypertrophy of the right ventricle is recorded with three methods of derivation in Samojloff's article (see his Figs. 20, 21 and 22). It is Einthoven's idea that, in hypertrophy of the right heart where R_3 is very high, the fibres of the conducting system carry the stimuli to the regions which are near the base of the heart, while in hypertrophy of the left heart with a negative R_3 the portions of the ventricle first stimulated by the conducting fibres lie nearer the apex of the heart.

Hypertrophy of the Left Ventricle.

Electrocardiograms from cases with hypertrophy of the left ventricle have been made by several observers. An interesting example is that shown in Figs. 29 and 30, taken

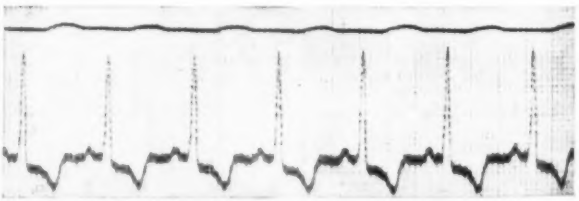

Fig. 29.—Electrocardiogram and carotid pulse from a patient with hypertrophy of the left ventricle due to aortic stenosis; D_1 (after Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, 569, Fig. 31).

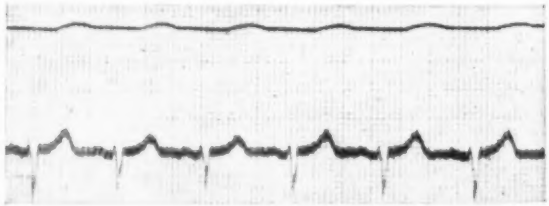

Fig. 30.—Electrocardiogram and carotid pulse in a case of aortic stenosis with hypertrophy of the left ventricle; D_3 (after Einthoven (W.), Weiteres über das Elektrokardiogramm, 1908, CXXII, 569, Fig. 30).

from a patient with aortic stenosis and hypertrophy of the left heart. Here with the first lead R is very high and T is negative, while with the third lead R is negative and T is positive. The importance of multiple derivations is especially well illustrated by these two curves.

In Figs. 18, 19 and 20 of Einthoven's article entitled *Le Télécardiogramme,* the curves from three patients with hypertrophy of the left heart are illustrated. With D_3 all of them yielded a negative R, while with D_1 all yielded a positive R. Similar curves are recorded by Samojloff in his Figs. 17, 18 and 19. R is positive in them with D_1 and D_2 and strongly negative with D_3.

BEHAVIOR OF THE T-WAVE IN MYOCARDIAL DISEASE.

In curves taken from normal hearts T_1 and T_2 are positive though T_3 may be either positive or negative. In cases of myocardial disease it has been a common finding to obtain curves in which the wave T was very low or even negative with D_1 or D_2 (Fig. 31). Einthoven has expressed the opinion that this finding always indicates a diseased heart though the pathological change may be only myocardial insufficiency or myocardial degeneration. This view has been supported by Kraus & Nicolai and by Samojloff. Recent investigations, however, have shown that a positive T-wave

FIG. 31.—Electrocardiogram with loss of T-wave in myocardial disease (after Kraus and Nicolai).

may be present even in severe myocardial disease and in marked myocardial insufficiency (Hoffmann). As yet the exact significance of the T-wave is very obscure.

THE ATYPICAL ELECTROCARDIOGRAMS YIELDED BY VENTRICULAR EXTRASYSTOLES.

Among the most interesting electrocardiographic curves obtained clinically are those yielded by hearts in which ventricular extrasystoles occur along with normal systoles. The extrasystolic curve presents a striking appearance in contrast with the typical electrocardiogram, for these atypical curves are produced by large potential differences which continue for a relatively long time. As a rule the electrocardiogram of the atypical heart contraction takes the form of a simple diphasic action-current due to a gradual advance of the excitation wave from one end of the ventricles to the other. The stimulus is not initiated proximal to the ventricles, but evidently begins in the ventricles themselves, sometimes near the base, sometimes near the apex, or probably sometimes in the right ventricle and sometimes in the left. Excellent examples of the curves from such a ventricular extrasystole by all three methods of derivation are shown in Fig. 32. The patient, a woman, A. v. Y., suffered from myocardial degeneration, and in the electrocardiogram of the ordinary beats of the heart the T-wave was sometimes doubled in D_2 (Fig. 32b). The extrasystole yields a wholly different curve from that of the ordinary systoles. There is no evidence of P-, R-, or T-waves, but instead an outspoken diphasic action current making a simple curve of two large waves, one being directed upward and the other downward. In D_1 (Fig. 32a) it is obvious that the origin of the wave is nearer to the right side than to the left side of the heart, while in D_2 (Fig. 32c) the curve indicates that the wave originated nearer the apex than the base. The fact that the two waves are lower in D_2 (Fig. 32b) than in D_1 and D_3 agrees with the assumption that the stimulus originated in the right ventricle near the apex; thence it advanced gradually in a direction toward the left and upward.

Now when the atypical heart-contraction begins near the

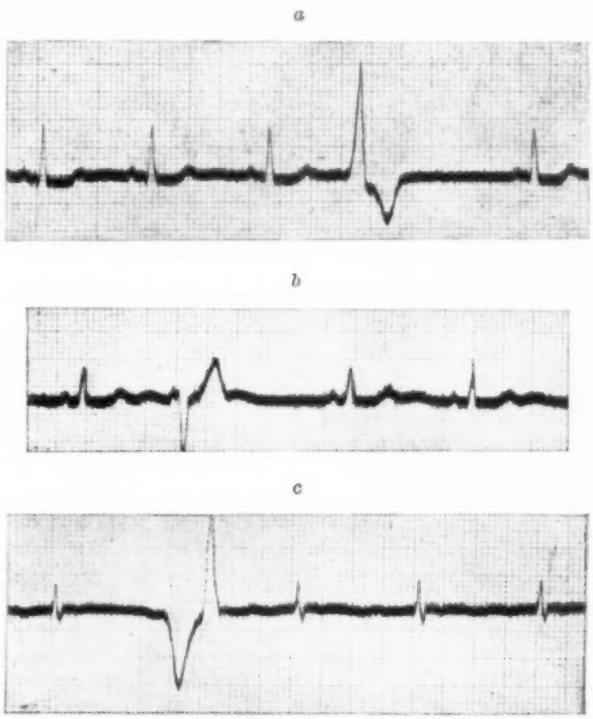

FIG. 32.—a, Curve showing an extrasystole or atypical heart contraction by D_1; b, Curve showing extrasystole or atypical heart contraction by D_2; c, Curve showing extrasystole or atypical heart contraction by D_3. Form of electrocardiogram in ventricular extrasystole or atypical heart contraction by the three principal methods of derivation (after Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, 579, Figs. 36, 37 and 38 combined into one figure).

base of the heart and advances toward the apex the curves obtained are quite different. In Fig. 33 are reproduced the electrocardiograms obtained from Einthoven's patient S. K., who suffered from a bigeminal arhythmia dependent upon regularly recurring extrasystoles. In Fig. 33a the curve obtained by D_1 is recorded, while in Fig. 33b that obtained by D_3 is given. For convenience in Fig. 33a an ordinate of 1 mm.$=10^{-4}$ volt, while in Fig. 33b an ordinate of 1 mm.

indicates a potential difference of 2×10^{-4} volt. The waves of the ordinary (normodromic) systoles are designated by the ordinary lettering *P, Q, R, S* and *T*. The waves of the atypical (allodromic) curves due to the extrasystoles are small in D_1, which indicates that the wave passed almost directly from the base toward the apex, while the minute elevation at *a* suggests that at this point the stimulus was probably transmitted from the ventricles to the atria.

There can be no doubt that the path through the heart muscle followed by the stimulus in such extrasystoles is wholly different from the path followed by the stimulus preceding ordinary beats of the heart. Whether the stimulus travels more slowly in such ventricular extrasystoles than in normal systoles is a mooted question. While the curve shows a long duration of the potential differences it is possible, as

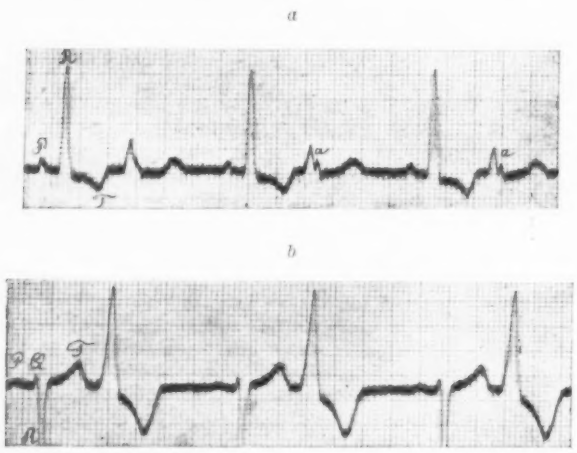

FIG. 33.—*a*, Curve of extrasystole, D_1; *b*, Curve of extrasystole, D_3. Abscissa 1 mm. = 0.04 sec.; ordinate 1 mm. = 2×10^{-4} volt. Forms of curve obtained from extrasystoles by the first and third methods of derivation (from Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, 581, Figs. 40 and 41 combined into one figure).

Einthoven suggests, that its peculiar extent is due less to slow progress than to the long path which it must follow from the apex to the base or in the reverse direction.

THE TACHYCARDIA OF EXOPHTHALMIC GOITRE AND THE PHYSIOLOGICAL TACHYCARDIA OF EXERCISE.

The first to publish electrocardiograms taken in a case of exophthalmic goitre was, so far as I know, Hoffmann, who found a high *T*-wave and a shortening of the ventricular portion of the ventricular electrical systole; that is, a lessening of the distance from the beginning of *Q* or *R* to the end of *T*.

We have obtained precisely similar curves in our clinic. The high *T*-wave is always a marked feature.

It is interesting to compare these curves from pathological tachycardias with the electrocardiogram obtained by Einthoven in the physiological tachycardia due to exercise (Fig. 34). In the tracing taken after exercise the heart is beating more frequently and the atria are stimulated before the ventricular electrical systole of the previous cardiac revolution has been completed, so that one obtains a superimposition of the atrial wave upon the ventricular curve, the former riding tile-like upon the latter. One notices also an enlargement of the *P*-wave and the *T*-wave in this physiological

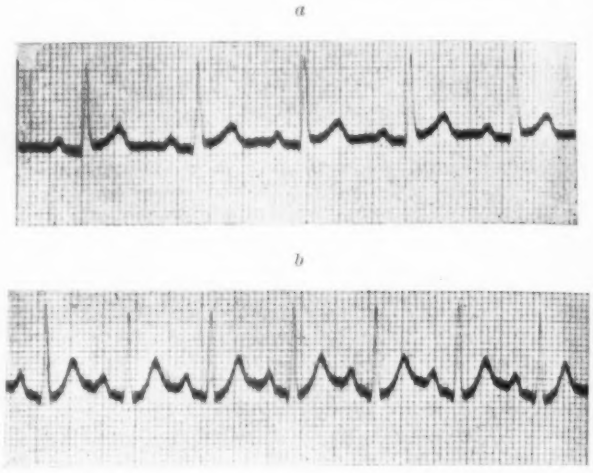

FIG. 34.—*a*, Curve with individual at rest; D_2; *b*, Curve from same individual after violent exertion; D_2. Curves contrastng the form of the electrocardiogram after rest with that after exertion (from Einthoven (W.), Weiteres über das Elektrokardiogramm, Pflüger's Arch., 1908, CXXII, 566, Figs. 26 and 27 combined into one figure.

tachycardia. *Q*, *R* and *S* are also somewhat more distinct than in the same patient at rest, but the changes are less striking than in *P* and *T*.

ELECTROCARDIOGRAMS FROM HEART-BLOCK CASES.

One approaches with a high degree of curiosity the records obtained by electrocardiographic methods from patients presenting symptoms of the Stokes-Adams syndrome. Curves of this sort have been recorded by Einthoven (Figs. 2 and 3 of the plate accompanying his article entitled *Le Télécardiogramme*, and Figs. 9 and 10 of Tafel 12 of his article in Bd. 122 of Pflüger's *Archiv*). Several cases of this sort have been studied also by Kraus and Nicolai. Recently we have secured electrocardiograms in Baltimore from a case of complete dissociation of atria and ventricles; the curves will be published in another article. Among the most interesting curves as yet published are those which accompany Pick's article and which I reproduce in Fig. 35. The patient, a man of 43, had three contractions of the atrium to one of the ventricle. The condition followed an acute endocarditis and had been in existence for fifteen years. Though the patient had a pulse rate of 30 he had kept up his work during a large part of this time. At one period he had one hundred and twenty attacks of syncope in twenty-four hours. Gradually the symptoms became less and there had been no attacks during the four years preceding the record here shown. Normal curves by D_1 and D_2 are shown above for comparison, while the curves from the heart-block case with the same two methods

of derivation are figured below. One can scarcely imagine a more beautiful method of demonstrating a complete or a partial dissociation between the activities of the atria and the ventricle. Though the comparative study of phlebograms, arteriograms and cardiograms are quite sufficient for the diagnosis, the mass of waves which one obtains with such records is very complex in contrast with the simplicity and elegance of the demonstration of dissociation which the electrocardiogram affords. In the figures, the atrial waves are indicated as *P* while the main ventricular wave is marked *R*. There are three times as many *P*-waves as *R*-waves and they bear no regular temporal relation to one another. In one

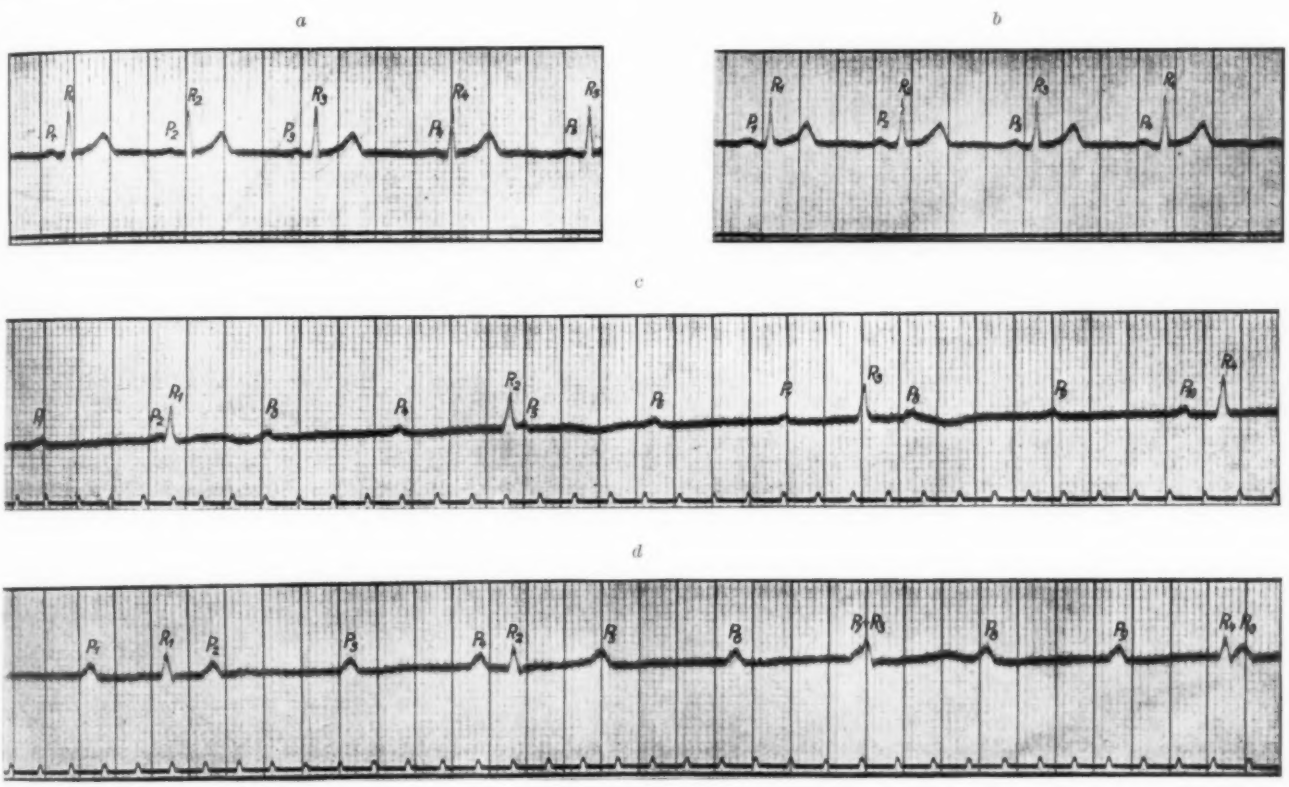

FIG. 35.—Pick's heart-block case. *a*, normal curve D_1; *b*, normal curve D_2; *c*, Case *N*, D_1; *d*, Case *N*, D_2.

place the ventricular wave coincides in time with the atrial wave (Fig. 35, P_7+V_3). An interesting fact in connection with these curves is the character of the ventricular waves. They are those of the typical electrocardiogram (normodromic) and not those of ventricular extrasystoles (allodromic). It will seem important, therefore, in heart-block cases to recognize the character of the spontaneous ventricular systoles as being wholly different from the ventricular extrasystoles which yield the simple diphasic curves with huge potential differences. It seems likely from this observation alone that the spontaneous systoles of the ventricle in the Stokes-Adams syndrome are initiated in the conducting apparatus close below the line which interrupts the continuity of the atrio-ventricular bundle and the path followed through the heart muscle is that traversed when the heart is beating normally.

As an example of the thorough working up of a case of heart-block by all the newer methods, the reader should consult the report made by Vaquez, Clerc and Esmein (1909).

We have recently had the opportunity, here in Baltimore, of making an electrocardiogram in a case of complete dissociation of the auricles and ventricles in a patient who had suffered but little inconvenience from his cardiac lesion. Though the slow pulse had existed for a long time, he had never had an attack of syncope. When first I saw the patient, a banker from a western State, he had been for some time under considerable mental and physical strain and presented in addition to his slow ventricular rhythm (normodromic beats) a large number of ventricular extrasystoles (allodromic beats). With rest in bed and a quiet environment these extrasystoles quickly disappeared, and when the electrocardiogram was taken one got only the *P*-waves of the atrial rhythm and the *R*- and *T*-waves of the dissociated spontaneous ventricular rhythm. It was surprising how well the patient got along in spite of his heart-block. Ordinarily ventricular extrasystoles are of litttle help in the mechanical work of the heart, but it seems probable that in certain heart-block cases the allodromia may prevent syncopal attacks.

In health, during increased work, the rate of the heart is

increased through the action of the accelerator fibers upon the sino-auricular node of Keith and Flack, but in heart-block the rhythm of the ventricles cannot be increased either directly through the accelerators or indirectly by the transmission of the impulses from the sino-auricular node through the His bundle to the ventricles. On the contrary, the simultaneous exaggerated innervation of the antagonistic N. vagus may tend somewhat to slow the rate of the ventricles. It may be that this stimulation of the vagus favors the irritability of the tertiary auxiliary excitation points, perhaps at the termini of Tawara's conduction system in the ventricular walls, and so permits of compensatory extrasystolic beats. Such an explanation has been offered by Nicolai in a case similar to the one I have mentioned above. In Fig. 36 is represented Nicolai's diagram illustrating his ideas of the re-

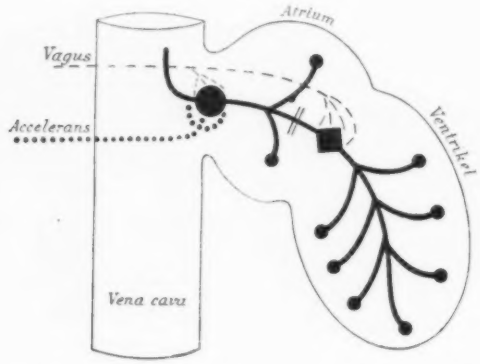

FIG. 36.—Scheme of the cardiac centers of the conduction system and the points upon which the extra-cardial regulatory nerves act (after Nicolai (G. F.), Deutsche med. Wchnschr., 1909, II, 2254, Fig. 1). ○, primary automatic rhythm center (Keith-Flack sinus node). □, secondary rhythm center (Aschoff-Tavara atrio-ventricular node). o, Tertiary centers (heart ganglia or musculature).

lations of the N. accelerans and the N. vagus to the primary (normal), secondary (vicarious) and tertiary (auxiliary) centers of cardiac excitation. In Fig. 37 are shown the electrocardiograms in Nicolai's case before and after work.

Of unusual interest in this connection are the hæmodynamic observations of Plesch. As students of cardiac pathology know, this investigator has worked out a method for measuring clinically the minute-volume of blood given out by the left ventricle. On the average in normal individuals this minute-volume amounts to four liters or about 60 cc. per systole when the body is at rest. During work twenty times as much may be needed and the increased minute-volume can be obtained either by increased systolic output or by a more rapid rate of the heart.

In Nicolai's case of heart-block the single systolic output was very large, amounting to 174 cc. instead of the normal 60 cc. The size of this output was doubtless related to the small number of systoles and was perhaps in part dependent upon the fact that the patient was anæmic, so that a normal minute-volume of four liters was insufficient for the oxidation-processes of the body. The minute-volume, as calculated by Plesch, amounted in this case to 7.6 liters. When this patient tried to work, the usual methods to which the heart resorts for increasing the minute-volume were not available; the frequency of the heart beat could not be increased in the ordinary way and the single systolic output had reached a maximum at rest. Ordinarily, therefore, one would expect that such a man, if he exerted himself, would suffer from the collapse of the typical Adams-Stokes syndrome. Syncope did not occur and the reason probably lay, as in my patient, in the development of the extrasystoles, whose systolic outputs, added to those of the more normal contractions, sufficed for the cerebral oxygen-supply. If these views are correct we

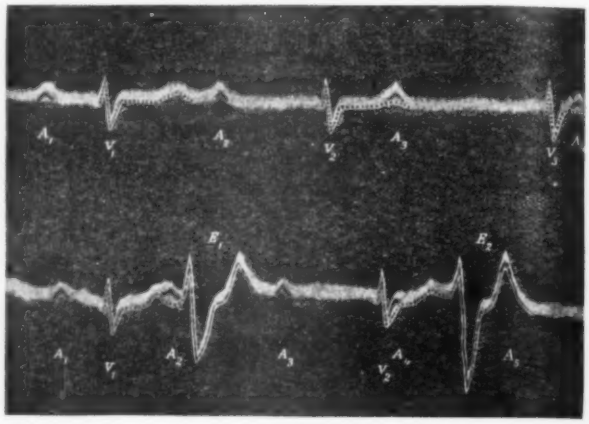

FIG. 37.—Electrocardiogram before (*I*) and after (*II*) work in a case of heart-block (after G. F. Nicolai). *A* = atrium contraction; *V* = ordinary ventricular beat (normodromic systole of secondary center); *E* = extrasystole (allodromic systole from tertiary center).

Curve I 40 *A* 32 *V* per minute.
Curve II 65 *A* 26 *V* 26 *E* per minute.
52

i. e.: *A* at rest = *A* at work = 4.
V at rest = *V* at work = 5.

Only a part of the original figure has been reproduced.

must recognize that extrasystoles may sometimes exercise a most important compensatory function.

CONGENITAL HEART DISEASE.

Curves from congenital heart disease showing peculiar *R*-waves and *T*-waves have been published by Einthoven (see Fig. 24 of his *Le Télécardiogramme* and Fig. 35 of his article in Pflüger's *Archiv*, Bd. CXXII). I shall not reproduce them here inasmuch as the exact nature of the congenital disease does not seem to have been clearly made out. Only where the clinical study has been controlled by autopsy could such curves have much value.

The same comment applies to Wandel's report of curves taken in a case of persistent Ductus Botalli; here, instead of a single *R*-wave, the initial ventricle-variation was multiple!

ATRIAL PARALYSIS AND ARHYTHMIA PERPETUA.

Those who have worked with phlebograms and arteriograms have been much interested during the past few years in the study of cases in which the atria are paralyzed and in which the pulsus irregularis perpetuus exists. It seems that the pulsus irregularis perpetuus is sometimes accompanied by paralysis of the atria, though not always. We have repeatedly taken curves from a patient under our observation at the Johns Hopkins Hospital, in which the perpetually irregular pulse was accompanied by atrial paralysis. One notes in the electrocardiograms the absence of the *P*-wave though *R* and *T* are well marked. The *R-R* interval shows remarkable variations in time. We have been able to observe cases in which atrial paralysis existed for a time (absence of *P*-wave) to disappear later (return of *P*-wave). Investigations of similar cases have been made by Einthoven (1906-07), Kraus and Nicolai (1907), Hering (1908) and by Rothberger and Winterberg (1909). These electrocardiographic studies

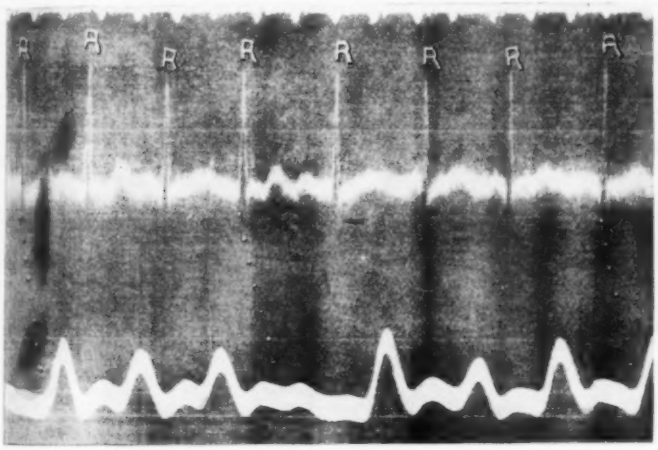

FIG. 38.—Electrocardiogram from a case of paroxysmal irregularity. The *P*-wave is absent and the *R-R* interval varies (after Thomas Lewis, Heart, 1910, I, Fig. 15). Only a part of the original figure is reproduced.

seem likely to bring the proof that in some of these cases fibrillation of the atrium exists (*vide infra*). The experimental investigations of Cushny and Edmunds, together with the electrocardiographic studies of Rothberger and Winterberg and of Lewis (1909-1910), promise to throw much new light on what has hitherto been a dark portion of cardiac arhythmia.

According to Kraus, electrograms indicate, in pulsus irregularis perpetuus, (1) the presence of groups of beats with falling or rising rhythm; (2) often combinations with atypical heart-beats due to stimuli abnormally located, though these atypical beats are less often ventricular extrasystoles than beats arising from stimulation of the Aschoff-Tawara node in the His bundle at the atrio-ventricular junction.

Lewis in London has recently (November, 1909) reported electrocardiographic observations upon atrial fibrillation. He, like Rothberger and Winterberg, believes it to be the cause of the pulsus irregularis perpetuus. The electrograms taken show, in addition to the *R*- and *T*-waves of the ventricular excitation, numerous small irregular elevations throughout the *T-R* interval (*i. e.*, between two ventricular excitations), which correspond to similar irregular waves obtained in animals in experimental atrial fibrillation. He suggests that James Mackenzie's nodal bradycardia may be a complete heart-block associated with fibrillation of the atria.

In a still later paper published in *Heart* (March 30, 1910), Lewis gives a very complete review of the whole subject based upon curves taken from thirty cases. In Fig. 38 a part of one of the characteristic curves is reproduced.

HEARTS OF NEURASTHENIC PATIENTS.

A very careful study of a large number of the out-patients in the neurological clinic in Berlin has been made by Nicolai and Simons. It has been suggested that the wave *S* of Einthoven (Nicolai's *Jp*) is especially marked in neurasthenic individuals, and Kraus had actually referred to it as the *nervöse Zacke*. Kraus had found this wave present not only in hypertrophic hearts, but in the hearts of children and young adults, especially in young females. Most of these patients presenting the marked wave were infantile or feminine and had labile vasomotors, indicating a predominance of the sympathetic activities over those of the regulators such as the vagus. The studies of Nicolai and Simons, however, have proved that many neurasthenic patients show no abnormality of the wave *S*.

HEARTS OF INFANTS.

It is interesting that Funaro and Nicolai found the *S*-wave (the so-called neurasthenic wave) well marked in forty-five sucklings from whom they took electrocardiograms! They think it possibly due in these infants to slight dislocation of the heart owing to a high position of the diaphragm. This peculiarity of the infantile electrocardiogram is said to disappear after the first year of life, except in children suffering from retarded development, in whom it may persist longer.

PAROXYSMAL TACHYCARDIA.

Electrocardiograms taken during an attack of paroxysmal tachycardia have been published by Hoffmann (1909) and also by Lewis (1909). The curves obtained by Lewis are particularly interesting and confirm his view that two fundamentally different forms of paroxysmal tachycardia exist, one (a) characterized by the persistence during the paroxysm of the presystolic contraction of the atrium (*atrial* or *auricular form*) and the other (b) by the absence of atrial contraction in the presystole, the atrium in reality contracting simultaneously with the ventricle or a little later (*nodal* or *ventricular form*).

Lewis has succeeded in producing a ventricular form of paroxysmal tachycardia in dogs. After severing all the nerves connecting the heart with the rest of the body, the paroxysm of tachycardia can be started by simply ligaturing the descending branch of the left coronary artery, or better still,

the trunk of the right coronary. In the tachycardia produced the ventricles contract first and the atria later, so that the form is ventricular (though not nodal).

GALLOP-RHYTHMS.

Rothberger of Vienna has studied electrocardiograms from a patient manifesting gallop-rhythm. The curves resemble so strikingly the curves obtained from experimental animals in which one branch of the His bundle has been cut below Tawara's node that this author is inclined to look upon gallop-rhythm as an evidence of univentricular conduction-system disturbance.

Electrocardiograms in Experimental Work.

The effects of rest, of exercise and of dislocation of the heart by the distended stomach, by pleural effusions and by mechanical means, have been studied especially by Hoffmann and by Einthoven, and some of the results obtained have been referred to above.

A number of observers, too, have worked upon the exposed heart of animals, leading off the currents directly from atrium or ventricle and attempting to throw light upon the normal electrocardiogram obtained by leading off from the extremities. Of the other experimental researches may be mentioned the effects upon the electrocardiogram of experimental hæmorrhage, of intoxications, of vagus stimulation, of injuries to the heart muscle (thermal, chemical, mechanical, electrical) and of fibrillation of the atria and ventricles.

HÆMORRHAGE.

The main effect of hæmorrhage on the electrocardiogram of the dog is a lowering of the *T*-wave, perhaps due to the lowered blood pressure (Einthoven). According to Kahn (1909) this lowering occurs only after some little time has elapsed; this author describes the series of changes in the electrogram which follow hæmorrhage due to section of the abdominal aorta.

CHLOROFORM POISONING.

The effects of chloroform poisoning have also been studied by Einthoven. The main effect is seen in the wave *T*, which is changed and may often be negative. In deep narcosis chloroform lengthens the *A-V interval* (that is, the lengthening of time between the end of *P* and the beginning of *Q* or *R*). If the chloroform be pushed still farther the activities of the ventricles and the atria may be partially or completely dissociated and extrasystoles may appear, yielding atypical electrocardiograms. These effects are all markedly increased if the vagus be stimulated during the administration of the anæsthetic. Einthoven suggests that later on surgeons may come to use the string galvanometer during anæsthesia in order to keep tab on the heart.

OTHER INTOXICATIONS.

Among the other poisons whose effects upon the electrocardiogram have been studied are strophanthin, digitalis, muscarin, adrenalin, diphtheria toxin and yohimbin. Work with these poisons has really only been begun and it is too early as yet to speak with any certainty regarding them. The details will be found in the publications of Kraus and Nicolai, Lewandowsky and Strubell.

VAGUS EFFECTS.

Very interesting observations upon the effects of vagus stimulation have been made by Gaskell, Gotch, Einthoven and H. E. Hering.

Cutting the vagus increases the rate of the heart owing to the loss of vagus tonus. In such a tachycardia the electrical waves due to the ventricle are not yet over when the next atrial wave begins, so that the atrial wave becomes superimposed upon the end of the preceding ventricular wave. Analyzing Einthoven's results one finds that the waves *Q* and *R* are very little altered, that *T* becomes a little smaller, *S* somewhat larger on cutting the vagi, but far the most important change is that in the wave *P*, which becomes almost three times as high as in the uninjured animal.

Another effect of section of the vagi is shortening of the heart pauses due to the tachycardia. The duration of the potential change in the atrium is very little altered, but the *A-V* interval is much diminished; in a normal animal it amounted to 0.13 seconds, while in an animal with cut vagi it was only 0.09 seconds. The *R-T* interval in the animal with uninjured vagi was 0.16 seconds, in the dog with sectioned vagi 0.13 seconds. In sum, then, the loss of vagus tonus leads to greater potential differences in the atrium, less potential differences in the ventricle, a slight shortening of the time of the atrial potential difference, a greater shortening of the time of ventricular differences and a shortened conductivity of impulse in the tissue between the atrium and the ventricle.

In contrast with these effects resulting from section of the vagi are those obtained by variable grades of stimulation of these nerves.

In Einthoven's experiments two striking effects of feeble stimulation of the vagus of the dog were observed; namely, lengthening of the heart pause with bradycardia, and decrease in the size of the *P*-wave. In addition to these two principal changes there was a slight increase in the distance between *R* and *T*.

On stronger stimulation of the vagus, sufficient to cause arrest of the heart, Einthoven observed a very marked effect upon the atrial electrogram. Sometimes the *P*-wave is simply diminished in height without undergoing marked change in form, but in other instances the form of the wave is much modified; instead of a single elevation above the zero line with fall again to that line, one sees a curve which falls below the abscissa after the wave to rise again thereto before the *R*-wave appears. One notices also a little lengthening of the time of the potential difference in the atria and also a slight lengthening of the *P-R* interval.

Sometimes a complete dissociation between the atria and ventricles results from strong vagus stimulation and this, together with a fall of blood pressure during the block, is well shown in Fig. 39. The peripheral end of the right vagus which had been cut through was stimulated by induction cur-

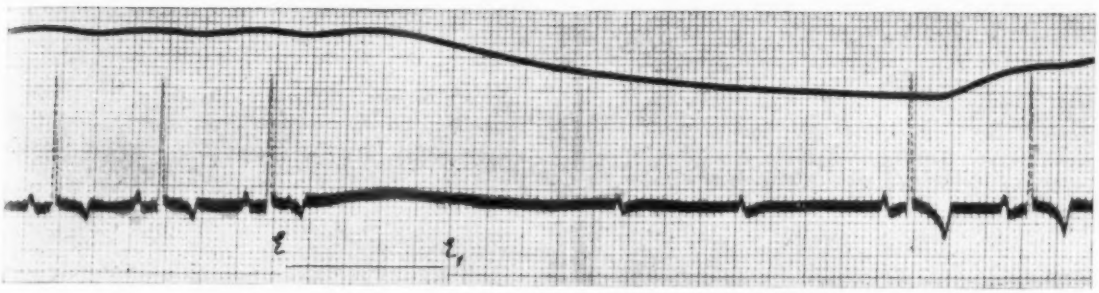

FIG. 39.—Effect of vagus stimulation upon the blood pressure curve and electrocardiogram in the dog; D_2 (after Einthoven (W.), Pflüger's Arch., 1908, CXXII, Taf. 11, Fig. 2). The vagus stimulation began at E and ended at E_1. Only a part of the original figure is reproduced.

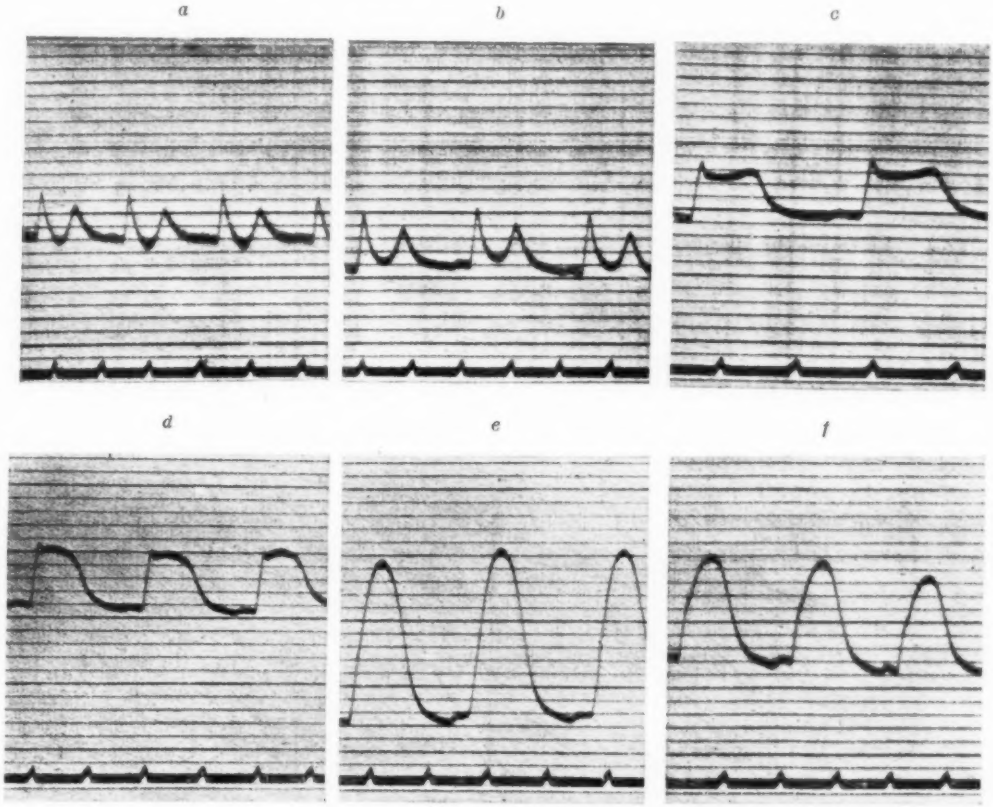

FIG. 40.—Electrocardiogram showing effect of destruction of portion of wall of left ventricle in the dog (after Eppinger and Rothberger, Wiener klin. Wchnschr., 1909, XXII, 1093).

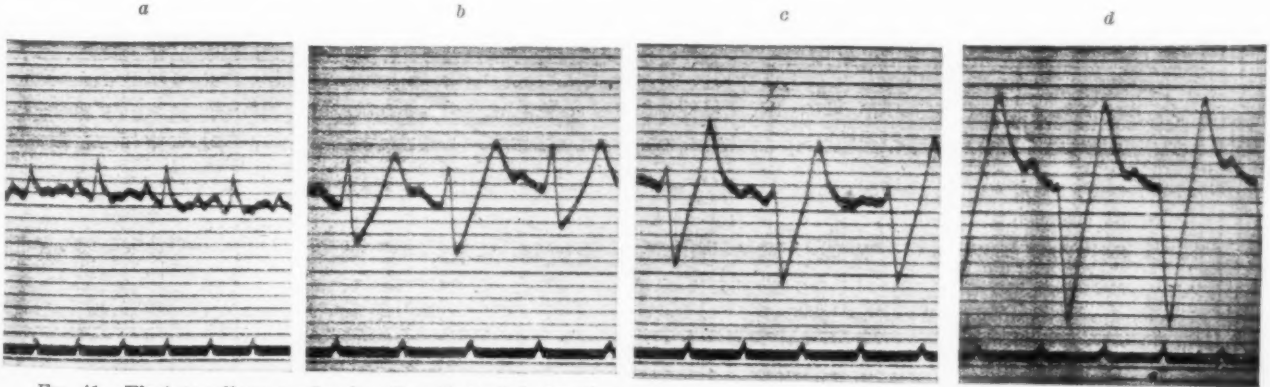

FIG. 41.—Electrocardiogram showing the effect of destruction of portion of wall of right ventricle in the dog (after Eppinger and Rothberger, Wiener klin. Wchnschr., 1909, XXII, 1094).

rents between E and E_1; blood pressure fell from 130 to 32 mm. of mercury; there was at first complete arrest of both atria and ventricles, followed by two atrial excitations which have no corresponding ventricular excitation; after this the regular sequence of atrial and ventricular excitation reappears. In the recovery from arrest of the heart from strong vagus stimulation the atria behave entirely differently from the ventricles. The atria evidently recover gradually, while the ventricles follow the "all or nothing" law. When the ventricular excitations begin the potential differences of the ventricles are as large as normal while those of the atria are still smaller than normal.

These results of Einthoven have recently (1909) been largely confirmed and somewhat extended by H. E. Hering.

INJURIES TO MYOCARDIUM.

Attempts have been made to injure various portions of the myocardium in order, if possible, to interrupt the course of the impulses through the heart muscle and so to modify the form of the electrocardiograms. Eppinger and Rothberger, by means of a cooling spray, froze different foci in the two ventricles and obtained certain modifications of the R- and T-waves. They also injected sublimate and silver nitrate by means of a long needle into the heart, causing necrosis, and got interesting modifications of the curve.

The immediate effect of the injection was a shower of extrasystoles, but in one or two minutes a stationary condition usually resulted. Occasionally death occurred from fibrillation of the ventricle.

In injuries to the left ventricle the main thing they discovered was that descent of the R-curve was made more difficult or hindered altogether (Fig. 40). The normal curve is shown at a, while at c the valley between R and T has almost disappeared. The authors got this effect thirteen times in twenty-five injections into the left ventricle. The results were the same whether they injected at the base or at the apex and the effect could never be produced by a superficial lesion or by injury to the papillary muscles.

Injections into the right ventricle yielded more variable results. The extreme effect is shown in Fig. 41. In a there is a fairly normal curve though the T-wave is split. In b the R-wave is larger and there is a large S-wave followed by a very large T. In c and d the changes are still greater; S and T have grown larger and R has finally disappeared and they got a curve like that of an extrasystole arising in the left ventricle (d). This curve differs from that of a ventricular extrasystole, however, since the P-wave is present. The effects produced by injuring the two ventricles are just opposite to one another.

On injection into the septum it made no difference whether the site of the injection were near the apex or near the base, but it made a great difference whether the site selected was midway between the two surfaces of the septum or nearer the interior of one of the ventricles. When the middle of the septum is injured the lesion resembles that due to injury of the left ventricle.

In general, Eppinger and Rothberger were struck by the fact that in these myocardial injuries sometimes very large foci had no effect upon the form of the curve, while in other instances very small foci had a marked effect. These differences were probably due to the degree in which the conduction-system in the heart was involved in the lesions. They subsequently tried cutting single portions of the conduction-system in curarized animals. Their curves obtained from section of the left and right branches respectively of the ventricular portions of the His bundle are reported to be very remarkable. These observers assert that on section of the left branch they got an atypical electrocardiogram similar to that of an extrasystole originating in the right ventricle, and on cutting the right branch an atypical electrocardiogram similar to that yielded by an extrasystole originating in the left ventricle, but in contrast to the atypical electrocardiograms yielded in man by ordinary extrasystoles the curves always presented, in addition, an atrial wave which was unaltered. On listening over hearts with one branch of the His bundle cut, they heard sounds resembling those of gallop-rhythm, and they hint that gallop-rhythm in man may depend upon injury to one or the other branch of the His bundle. They have obtained a similar curve from a patient during life; the man was studied during several months and presented a constant form of electrocardiogram. At autopsy a large myocarditic focus was found in the septum and the naked-eye examination revealed apparently an interruption of the right branch of the bundle; the microscopic study has not yet been reported.

It is interesting that in experimental block, due to section of the His bundle, vagus stimulation causes slowing of the atrial rhythm, but has no effect, they assert, upon the spontaneous rhythm of the ventricle. Nicolai, on the contrary, finds some slowing of the ventricle in complete heart-block in human beings when the patient works; here the N. accelerans, being stimulated, hurries the rate of the atria, while simultaneous stimulation of the antagonistic N. vagus slows the dissociated ventricles and sometimes brings out compensatory ventricular extrasystoles (*vide supra*).

EXPERIMENTAL PULSUS ALTERNANS.

A good deal of experimental work has been done in the last few years upon the production of disturbances of contractility of the heart as manifested in the form of pulsus alternans. One of the methods of producing this change in contractility consists in the administration of glyoxylic acid. In animals so intoxicated Hering has taken electrocardiograms; he found the typical form though the waves were low; in other words, in pulsus alternans we have, during the feeble systole, to deal, he believes, merely with a hyposystole, produced through stimulation of the regular conduction-system, not with a ventricular extrasystole. In the feeble systole the electrical changes may be large when the effects seen in mechanical registration are small. The waves R and T may be both affected or either one may be more involved than the other.

EXPERIMENTAL EXTRASYSTOLES.

These have been studied with the aid of the string galvanometer by Einthoven, Nicolai, and especially recently by Kahn. Extrasystoles may be atrial, fascicular or ventricular in origin. To summarize the results of these studies it may be said that artificial stimuli applied to the walls of the ventricle of experimental animals yield atypical electrocardiograms. In other words, the contractions resulting from such stimulation correspond more or less closely to those of extrasystoles, which occur spontaneously, rather than to those of normal heartbeats. Kahn found that stimulation of the base of the right ventricle and of the apex of the right ventricle yield very similar curves, while stimulation of the apex of the left ventricle yields a curve in which the waves are in the opposite direction. There is a tendency, therefore, at present to assume, that in extrasystoles yielding atypical electrocardiograms, if the first wave be up and the second down the origin is to be looked for in the right ventricle, while when the opposite is the case (first wave down and second wave up) the source of the extrasystole is to be sought in the left ventricle. The subject, however, needs further experimental study, since extrasystoles occurring spontaneously in man may conceivably have their origin in stimuli arising near the endocardium, while in experimental animals the electrical stimulus has, as a rule, been applied to the external surface of the ventricles.

The idea that there are uniform types of electrocardiograms of extrasystoles arising in the right and left ventricle respectively is combated by good observers (Kraus and Nicolai; T. Lewis) on the ground both of observations on human beings and of animal experiments. The form of the atypical curve obtained depends, Lewis believes, much more upon the phase of diastole in which the extrasystole originates, and a form thus arising may be further complicated by the superimposition upon it of a curve due to a normal excitation. An extrasystolic curve is identical in length, he asserts, with the curve of a normal excitation. He finds that there are a series of special varieties of electrocardiogram each corresponding to excitation of the atrium in a particular region. Thus he got different kinds of *P*-waves, that arising on stimulation of the vena cava superior resembling most closely the *P* of typical electrocardiograms.

The ventricular contractions which follow upon extra beats of the atrium (so-called auricular extrasystoles) vary according to the particular time in ventricular diastole in which the excitation impinges upon the ventricle; the *R*-wave is often altered and the *T*-wave is inverted if at the beginning of diastole or diminished at the end thereof. The interval between *P* and *R* is often prolonged in the precocious auricular extrasystole. Lewis emphasizes the constancy of form of extrasystoles when observed for months in the same individual, a fact which points, in his opinion, (1) to a constant cause, and (2) to a small myocardial area in which the abnormal influence is felt.

Kraus and Nicolai have maintained that the ventricular electrocardiogram following upon an auricular extrasystole differs according as the extrasystole has been produced experimentally in the right atrium or in the left atrium.

FIBRILLATION OF THE ATRIA AND VENTRICLES.

The important facts previous to electrocardiographic studies regarding fibrillation of the atria are summarized in Hirschfelder's article published in this Bulletin in November, 1908. An electrocardiogram of the ventricles in fibrillation was taken by Kahn in 1909 (Pflüger's *Archiv*, Vol. 126).

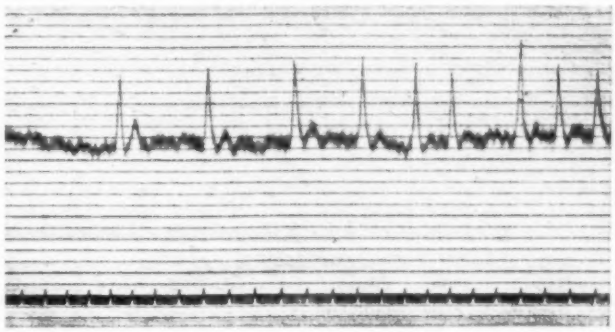

FIG. 42.—Electrocardiogram from experimental fibrillation of the atrium in the dog. The pulse has the characters of the pulsus irregularis perpetuus in man (after Rothberger and Winterberg, Wiener klin. Wchnschr., 1909, XXII, 841, Fig. 1).

In the same year Rothberger and Winterberg, using curarized animals, found that a brief faradic stimulus of two or three seconds, combined with vagus excitation, would cause fibrillation of the atria which would last for some time or even remain permanent. Toxic stimulation of the vagus with drugs like pilocarpin, nicotin, physostigmin or muscarin also

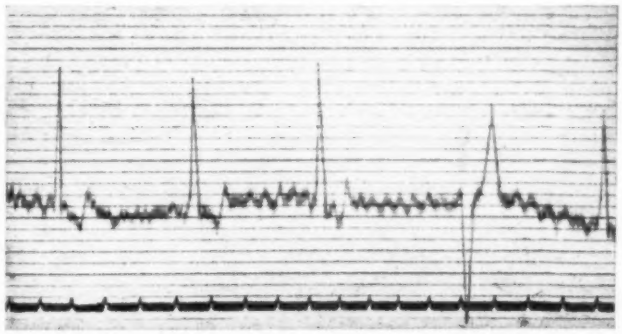

FIG. 43.—Electrocardiogram showing coarser form of curve sometimes obtained in experimental atrial fibrillation (after Rothberger and Winterberg, Wiener klin. Wchnschr., 1909, XXII, 842, Fig. 4).

caused atrial fibrillation. Electrocardiographic curves made by D_2 showed complete absence of the *P*-wave and a tremor of the string all through the resting intervals. The *R*-wave was free from the tremor, though the *T*-wave sometimes showed it. In Fig. 42 a characteristic arhythmia shown by the variable length of the *R-R* intervals is observable; the *P*-wave is absent; the *T*-wave is distinct. In the pauses larger and smaller waves, which the authors think due to fibrilla-

tion, can be made out. The coarser form of atrial fibrillation is represented in Fig. 43. The authors also show curves from two patients with permanent arhythmia; the tracings in their opinion prove the presence of atrial fibrillation.

The most elaborate study of atrial fibrillation thus far made is that of Thomas Lewis (1910). Rendering dogs insensitive with morphin and paraldehyd as well as by deep surgical anæsthesia he produced fibrillation of the atrium by faradic stimulation of one auricular appendix. He drew off the currents from the heart in different ways. The oscillations obtained were unique, occurring in no other experimental condition. They are illustrated in Figs. 20 and 22 accompanying his article in Vol. I, No. 4, of *Heart*. The variations of the current succeed each other rapidly at a rate of from 500 to 900 per minute. They replace the *P*-wave of a normal curve and distort the *T*-wave in the same way as that already seen in curves of pulsus irregularis perpetuus in man. The waves continue throughout the whole of the cardiac cycle. These waves are present only when the atrium is in fibrillation and they disappear entirely in the same animals if the normal rhythm becomes re-established. It would seem that Lewis, on the one hand, and Rothberger and Winterberg, on the other, have arrived at almost identical results independently of one another.

THE WAVES OF THE ELECTROGRAM AND INTRACARDIAC PRESSURE.

The relation of the waves of the electrogram to events in the cardiac cycle in the dog has been studied by Kahn (Fig. 44). He finds that the *P*-wave coincides with or precedes slightly the apex of the curve of intra-atrial tension. The wave *R* is produced just before the beginning of ventricular activity and disappears during the tension-time; it is all over at the beginning of the expulsion-time. The *T*-wave, on the contrary, occurs during the expulsion-time; it is synchronous with the plateau so often seen on the curve of intraventricular pressure. On making cardiophonograms simultaneously with electrocardiograms, Kahn finds, in the dog, that the first sound of the heart occurs in the interval between *R* and *T*; it begins synchronously with the ascent of the curve of intraventricular pressure, just at the moment when the *R*-wave ceases, and the sound is over a little before the *T*-wave appears. The second sound of the heart begins about one-twentieth of a second after the end of the *T*-wave.

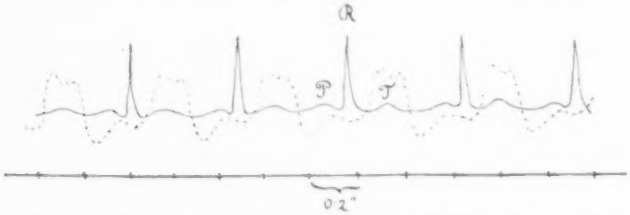

FIG. 44.—Scheme showing the relation of the waves of the electrocardiogram to the curves of intra-ventricular pressure in the dog (after R. H. Kahn, Pflüger's Arch., 1909, CXXVI, 209, Fig. 16).

INTERPRETATION OF THE TYPICAL ELECTROCARDIOGRAM.

Various attempts have been made to explain the form of the electrocardiogram on the basis of the course followed by the excitation through the heart muscle. For a time it was thought that the ventricular portion of the electrocardiogram could be explained by assuming that it represents the algebraic sum of the curves resulting from the negativity of the base and the negativity of the apex. The difficulty, however, was to explain the *T*-wave, or in other words, why in such a resultant curve there should be two phases in the same direction. Bayliss and Starling thought they had found the solution in the assumption that the excitation of the base of the heart lasts longer than that at the apex. According to their view the ventricular portion of the curve begins with the negativity of the base. This produces the quick excursion *R*, to be followed by a rapid sinking due to the negativity of the apex. The wave *T* would then be due in their opinion to the fact that the base remains negative after the excitation process at the apex has ceased.

To explain the longer negativity of the base Gotch has put forward a view based upon the embryological development of the heart. As is well known, the heart is derived in the embryo from a simple tube which later becomes curved in the form of a loop. The apex of the ventricle corresponds more or less to the middle of this loop. The atria and part of the bases of both right and left ventricle belong to the beginning of the loop, while the region of the aortic bulb at the base corresponds to the end of the loop. If *a* be the base of the ventricle continuous with the atria and *b* the part of the base corresponding to the pulmonary artery and aorta and *c* to the apex of the heart, the excitation according to Gotch's view passes from *a* through *c* to *b*. In electrocardiography *a* and *b* are connected with one end of the galvanometer and *c* with the other. Thus, according to Gotch's ideas, the base of the heart remains negative for a longer time than the apex, not because the excitation process remains longer in one and the same spot, but because different parts of the base are excited at different times. If Gotch be right, then the wave *R* is due to the part of the base we have designated *a* and the wave *T* to the part of the base we have designated *b*. The stretch between *R* and *T* would then correspond to the period during which base and apex are simultaneously negative. As Gotch points out, the spread of the excitation in the heart must be more complex than that in a simple linear excitable structure, though the scheme of such a simple structure may help us to understand it.

Nicolai bases his explanation of the form of the electrocardiogram upon the newer ideas of the conduction path followed by the excitation process in the heart of man and higher animals. It is now generally believed that the atria are connected with the ventricles only by the atrio-ventricular bundle of His and its radiations, which, as Tawara has shown, become continuous with the Purkinje fibers and the papillary system; the papillary muscles in turn are connected with the external spiral fibers of the ventricle on the one hand and

with the circular muscle (*Treibwerk*) of the heart (Fig. 45). The excitation seems to pass from the atria to the papillary system and is conducted along this from the base of the ventricles to the apex and then extends from the apex into the spiral and circular fibers, finally returning to the base. Until the papillary system is reached the excitation follows a simple, undivided path and so might be expected to give rise to a diphasic current with opposite phases. According to Nicolai *R* and *S* are two such phases. The reason why *S* is followed by a horizontal stretch lies, in Nicolai's opinion, in the combined excitation of the spiral and circular fibers, since the action-currents thus set up reciprocally compensate for one another. When the excitation finally reaches the base again, so that the latter becomes strongly negative, the *T*-wave arises. Then all the activity of the heart muscle ceases during the pause until the next atrial excitation is indicated by the following *P*-wave.

According to Einthoven the *P*-wave is due to excitation of the atria. The horizontal stretch between *P* and *Q* is due to

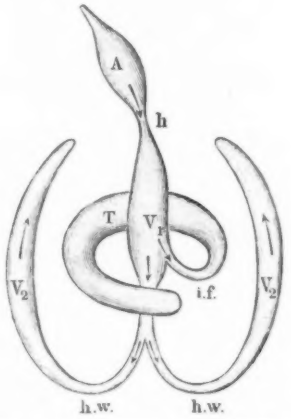

FIG. 45.—**Scheme of the course of conduction in the cardiac muscle (after G. F. Nicolai).** *A*, **atrium;** *h*, **His bundle;** V_1, **papillary muscles;** V_2, **spiral fibers of ventricles;** *T*, **circular fibers or Treibwerck).**

the passage of the excitation through the His bundle, during which the action-currents are so slight as not to register. Thence the excitation process is distributed to the walls of the ventricles, but in Einthoven's opinion a very large number of spots over the surface of the ventricle are simultaneously stimulated. The waves *Q*, *R* and *S* are the result. He thinks that if the stimulus happens to start close to the apex or in the left ventricle a *Q*-wave appears, while *Q* is absent if other spots in the ventricle are first excited. The excitation of the right ventricle, and especially of portions of the ventricular muscle at the base of the heart, gives rise to the *R*-wave, and the fact that this is immediately followed by an *S*-wave indicates, in his opinion, that almost immediately afterward the excitation of the left ventricle and of various spots near the apex of the heart got the upper hand. Then follows the horizontal stretch between *S* and *T* due, Einthoven thinks, to a rather even distribution of the excitation process over the whole ventricular walls. Should this general excitation stop at one time there is no *T*-wave, a phenomenon sometimes met with in degeneration or insufficiency of the heart. If the right ventricle stays contracted longer than the left, we get an upward *T*-wave in the first and second derivations, as is seen in all typical electrocardiograms. If the base of the heart stays contracted longer than the apex, we get an upward *T*-wave with D_3, while a downward wave with D_3 shows that the apex is longer contracted than the base. Einthoven states that in normal hearts the *T*-wave with D_3 may be either positive or negative, while with D_1 and D_2 it is always positive, higher after exertion and less marked when the heart is injured. A striking difference between Nicolai's explanation and Einthoven's is the difference of opinion regarding the waves *R* and *S*. While Nicolai assumes that this portion of the curve is a diphasic curve due to the spread of the excitation in a linear structure, Einthoven thinks that the appearance of this portion of the curve depends upon the inequality of excitation of various portions of the ventricle as a whole.

The similarity of the so-called atypical electrocardiogram (ventricular extrasystoles) to simple diphasic curves is very striking. Such curves are probably, Einthoven believes, due to the gradual advance of an excitation process from one end of a ventricle to the other. The stimulus here follows a course wholly different from that preceding normal contractions of the heart. It begins in the ventricles themselves, either close to the base or close to the apex, and may be propagated from the ventricles to the atria.

A somewhat different explanation of the form of the electrocardiogram from those offered above is to be found in the writings of Eppinger and Rothberger. Basing their views upon their experiments in which they injected sublimate and silver nitrate into the walls of the right and left ventricles they come to the following conclusions: The ascent of the *R*-wave is synchronous with the beginning of the excitation in the actual wall of the ventricle, whereas the pause between *P* and *R* includes, they believe, the whole period of excitation and conduction from the wall of the atrium to the termination of Tawara's conduction-system. This process of stimulus-conduction is not evident in any way in the electrocardiogram. Only on the arrival of this stimulus to a whole series of points upon the inner walls of the ventricles at the termini of the conduction-system does the ventricular part of the electrocardiogram begin. From this moment on (or even a little earlier if a *Q*-wave is present) up to the end of the *T*-wave the electrocardiographic curve represents, they say, the resultant of two antagonistic forces, the one sending a wave up lasting longer than that tending to send a wave down. It is probable, they think, that each of these forces is in turn the resultant of a large number of electrical forces corresponding to the multiple sites of stimulation. It is believed further by Eppinger and Rothberger that these two practically antagonistic forces correspond to the two main subdivisions of the cardiac muscle, the longitudinal (or spiral) fibers and the circular fibers. The circular fibers lie chiefly in the wall of the left ventricle; the longitudinal fibers are present in both

right and left ventricles. In the left ventricle the tissue at the apex and the papillary system are composed of longitudinal fibers. In the right ventricle nearly all of the wall is composed of these fibers, though one must bear in mind that the direction of the longitudinal muscle fibers is somewhat different in the part of the right ventricle into which the right atrium pours its blood from that of the longitudinal fibers in the portion of the same ventricle corresponding to the pulmonary infundibulum.

The longitudinal fibers are antagonists of the circular fibers; whereas the latter narrow and lengthen the heart, the former shorten and widen it. The two sets of fibers acting together bring about the greatest possible diminution of intraventricular space. Eppinger and Rothberger believe that these antagonistic muscles may be responsible for opposite effects in the electrocardiogram. It is the circular fibers, they think, which cause descent of the curve and the longitudinal fibers which bring about ascent thereof. If you destroy one set of these fibers with silver nitrate the other set will predominate. These ideas correspond to the electrocardiographic curves recorded in their experiments and they believe that the antagonism of the two ventricles in the electrocardiogram is dependent more upon the difference in anatomical structure than upon relations to base and apex.

All are agreed that clinical cases presenting hypertrophy of the right ventricle yield a large *R*-wave while hypertrophy of the left ventricle expresses itself in the form of a large *S*-wave. In the former instance the longitudinal system of fibers would be increased, while in the latter the circular.

These authors fall back upon the same hypothesis to explain the forms of the atypical curves associated with ventricular extrasystoles. If the extrasystole starts in the right ventricle and extends from it to the left there will be first a large *R*-wave on account of the predominant direction of longitudinal fibers, followed later by a large *S*-wave due to the extension of the excitation to the circular fibers of the left ventricle; similarly, when the extrasystole arises in the left ventricle the first large wave of the atypical electrocardiogram will be in the downward direction, to be followed later by a second large wave in the upward direction.

Since the longitudinal fibers of both ventricles contract before the circular fibers of the left ventricle the reason for the early appearance of the *R*-wave is, they think, explained.

The sudden fall of the *R*-wave is due, they think, to the sudden arrival of the excitation in the circular fibers. If the latter be destroyed, as in their silver nitrate experiments, there is no descent of the *R*-wave until much later.

Eppinger and Rothberger in their descriptions sometimes fall into an error of which they accuse other authors; namely, the confounding of the phenomenon of contraction with that of excitation. If one bear this fact in mind, however, it is easy to understand their meaning and certainly the results of their experiments are most suggestive.

No satisfactory explanation of the *T*-wave has, as yet, been given. Eppinger and Rothberger are much impressed by the fact that freezing of the surface of the ventricle affects only the *T*-wave and they believe, therefore, that the presence of this wave can have nothing to do with the excitation of the deeper muscular layers.

From the whole discussion it is obvious that much more work must be done before we shall attain to unanimity of opinion regarding the interpretation of the form of the typical electrocardiogram.

Phonocardiograms.

Another advance in cardiac investigation of recent date should be referred to briefly, namely, phonocardiogram-work.

Fig. 46.

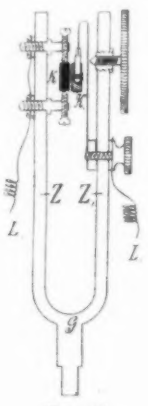

Fig. 47.

Fig. 46.—Resonance apparatus for strengthening the heart sounds. *St.*, stethoscope (after Hürthle).

Fig. 47.—Microphone for the registration of the heart sounds (after Hürthle).

The present status of the subject is described in the pamphlet of Otto Weiss[6] which should be consulted for details; here I shall call attention to the more interesting points only.

A knowledge of the exact relations of the contractions of the heart muscle and the moments when the heart sounds begin is of great importance for the accurate diagnosis of

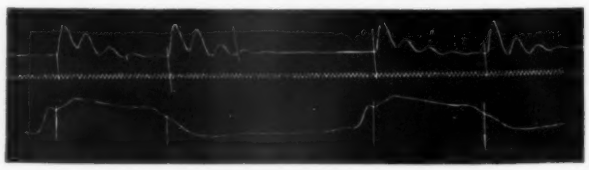

Fig. 48.—Registration of the heart sounds by Hürthle's method. In the upper curve the heart sounds are registered; the middle curve shows the time in one-hundredths of a second; the lower curve is the cardiogram.

cardiovascular conditions and efforts have, therefore, for a long time been made to register the heart sounds by mechanical means. The small energy of the sounds has made this very difficult, especially as it has been desired to have methods independent of the subjective reactions of the listening observer, methods which will have all the precision and objectivity of purely physical procedures.

[6] Weiss (Otto), Phonokardiogramme, Jena, 1909.

The subjective "marking method" which has been most used is that of Martius; it was of value especially in the analysis of clinical cardiograms but its faults have been pointed out especially by Hürthle.

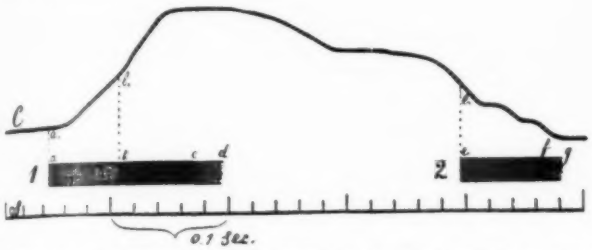

FIG. 49.—Temporal relations between the heart sounds and the cardiogram in man (after Einthoven). *C*, cardiogram; *I*, first heart sound; *II*, second heart sound.

In working out objective methods for registering the heart sounds it was necessary to transfer the sound-vibrations to some apparatus which would be set into sympathetic vibration (by resonance) and then to register these. The difficulties in the way were twofold: (1) the existence of vibrations of the chest wall other than those due to the heart sounds, and (2) the small amount of energy represented by the heart sounds themselves. Both difficulties have been overcome, the latter by devising receiving and recording apparatus of extreme delicacy. Three different investigators—Hürthle, Einthoven and Holowinski—have employed methods in which the sounds are received by means of a microphone.

Hürthle receives the heart sounds by a stethoscope (*St*) connected with a resonance-apparatus, which magnifies the amplitude of the vibrations (Fig. 46); the enlarged vibrations then act upon the handle *G* of a wooden tuning fork, with the arms *Z* and Z_1, the latter being set into vibration in the same tempo; the vibrations of the arms of the fork excite

FIG. 53.—Registration of human heart sounds by Holowinski's method. Only a part of the author's figure is reproduced.

the microphone (Fig. 47); this sets in action an electromagnetic signal-apparatus and the movements are transferred to a pantograph of Marey and registered (Fig. 48).

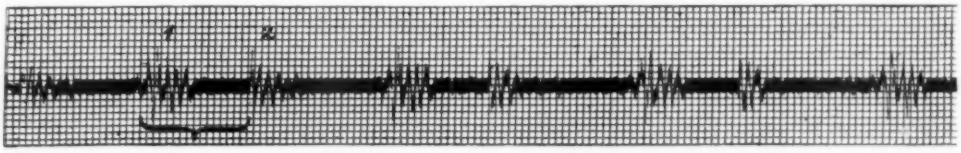

FIG. 50.—Registration of the apical heart sounds (after Einthoven). *I*, first heart sound; *II*, second sound.

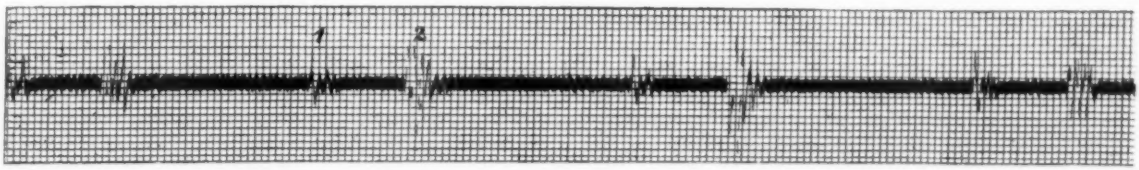

FIG. 51.—Registration of the sounds over the pulmonic area in man (after Einthoven). *I*, first sound; *II*, second sound.

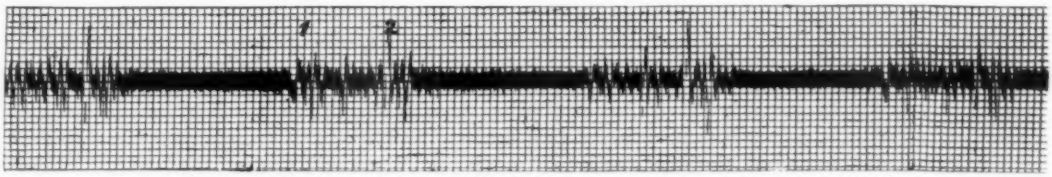

FIG. 52.—Registration of systolic heart murmur (after Einthoven). *I*, first sound; *II*, second sound.

Einthoven also receives the sounds by a microphone. At first he used for registration the capillary electrometer, but later employed the more delicate string galvanometer. His findings of the relation of the heart sounds are shown in Fig. 49. In Figs. 50 and 51 the differences in intensity and duration of the heart sounds at the apex and at the base of the heart are well illustrated. In Fig. 52 is reproduced Einthoven's findings in a case of mitral, insufficiency with systolic murmur. In Fig. 2 of my Jerome Cochran lecture (this Bulletin, 1909, p. 299) I have introduced one of Einthoven's phonocardiograms showing the position of the normal "third sound" of the heart. One great difficulty in working with the microphone lies in the necessity of making the ob-

servations in an absolutely quiet place; the vibrations of an elevator or of people walking about in the neighborhood disturb the records.

Holowinski also uses a microphone as a receiver of the heart sounds, but records them with the aid of a so-called "optical telephone." The method depends upon an application of the interference-rings of Newton; the changes in the rings are photographed, as shown in Fig. 53. For the details of the method Holowinski's article should be consulted.

FIG. 54.—Registration of human heart sounds by Marbe's method. *I*, first sound; *II*, second sound.

Marbe has used an entirely different objective method for recording the heart sounds. Recalling König's studies on the transfer of oscillations of a tambour to a gas flame of great sensibility he applied his instrument to the chest over the heart, and lighting the acetylene gas, passed a paper through the sooty flame; he got very good records of the heart sounds in the form of sooty rings as shown in the tracing (Fig. 54). A record has been made by Roos with this method from a patient with stenosis and insufficiency of the mitral valve.

A third principle—that of registering *directly* the oscillations of the sound-receiving membrane—has been utilized by O. Frank, by Gerhartz and by O. Weiss. The most important result of the application of the principle seems to be the invention of the *phonoscope* by Weiss. This investigator receives the sounds on a soap bubble, a membrane which exceeds in delicacy even the most sensitive microphone as yet devised. The difficulty of registering the oscillations of such a fragile and sensitive structure is obvious, but Weiss overcame it in the following way: He placed one end of a silvered glass thread bent at a right angle (0.01 mm. in diameter, weighing 0.0000035 gm.) in the center of the soap bubble, the other end being fastened in a holder; the oscillating bubble transfers its vibrations to the glass lever and the movements of the latter are registered photographically. Weiss gives an exact description of this phonoscope in his monograph; the apparatus is pictured in Figs. 55 and 56. In order that the vibrations of the heart sounds only shall effect the soap bubble, Weiss excludes the slow air-movements due to the chest wall (heart impulse) by placing the patient in a large iron guard containing a receiving-funnel which is pressed against his chest; the tube from this funnel projects in the phonoscope tube, but a space of about 4 mm. play is left between the two tubes. By such an unclosed connection of the sound-conducting apparatus with the phonoscope, the disturbing effects of the chest-wall vibrations are prevented.

The relations between the heart sounds and the different phases of the cardiogram tracing seem to be inconstant, a finding by Weiss, which is in accord with general clinical experience regarding the uncertainties of cardiograms. On the

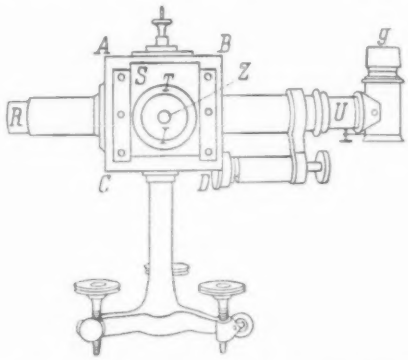

FIG. 55.—The phonoscope (after O. Weiss, Phonokardiogramme, Jena, 1909, 23, Fig. 20).

other hand, the temporal relations between the carotid pulse and the heart sounds are peculiarly constant in health; the time elapsing between the beginning of the first heart sound and the ascent of the carotid pulse amounts to 6.75 or 7.75

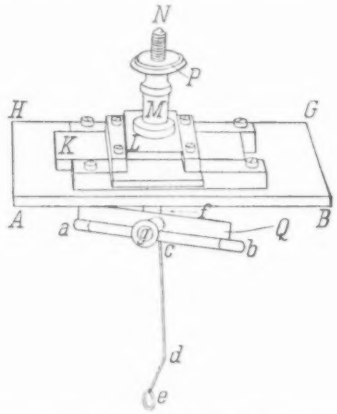

FIG. 56.—View of the upper part of the phonoscope (after O. Weiss, Phonokardiogramme, Jena, 1909, 23, Fig. 21).

hundredths of a second (Fig. 57). Weiss has been able with his method to record the fœtal heart sounds in a pregnant woman; in the case he examined the rate was 147 beats per

FIG. 57.—Registration of heart sounds in man by Weiss's method. The curve of the carotid pulse is shown above, the phonocardiogram in the middle and the time markings of 0.01 sec. below (after O. Weiss, Phonokardiogramme, Jena, 1909, 25, Fig. 24). Curves are to be read from right to left.

minute, the systole lasting 18.2 and the diastole 22.6 hundredths of a second.

Important as these results of Weiss are for physiology, to

us clinicians the findings of Joachim with the same method in pathological hearts are even more interesting. Joachim's studies include observations in the sounds and their temporal relations to the carotid pulse in cases of (1) mitral insufficiency; (2) mitral stenosis; (3) aortic insufficiency; (4)

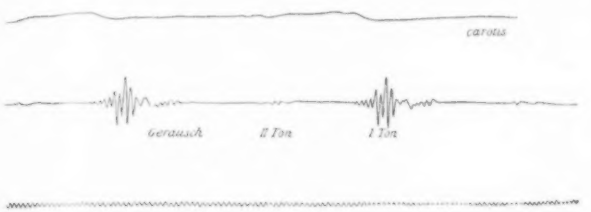

FIG. 58.—Phonocardiogram in mitral stenosis. Carotid pulse tracing above; time markings of 0.01 sec. below (after O. Weiss, Phonokardiogramme, Jena, 1909, 29, Fig. 30).

combined stenosis and insufficiency at the aortic orifice, and (5) functional (anæmic) murmurs. Doublings and splittings of the heart tones have also been studied in this way.

In Figs. 58 and 59 I have introduced two curves illus-

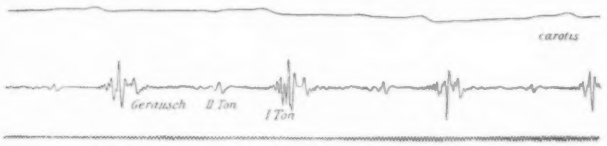

FIG. 59.—Phonocardiogram in another case of mitral stenosis (after O. Weiss).

trating mitral stenosis; they are very characteristic—one could make the diagnosis from the curves alone. In Fig. 58 the murmur is presystolic, while in Fig. 59 it lasts through the whole of diastole (note that these tracings are to be read from right to left).

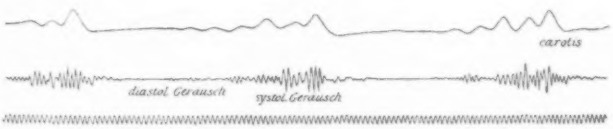

FIG. 60.—Phonocardiogram in aortic stenosis with aortic insufficiency. Arteriogram above (after O. Weiss).

A patient with aortic stenosis and insufficiency yielded the curves shown in Fig. 60. It is seen that the systolic murmur here is maximal at the time the carotid pulse is maximal. In mitral insufficiency the systolic murmur is maximal be-

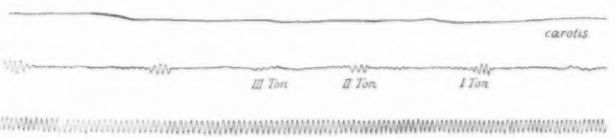

FIG. 61.—Phonocardiogram of three-time rhythm (protodiastolic gallop) (after O. Weiss).

fore the pulse appears in the carotid. These results confirm, therefore, von Noorden's view of the temporal discrepancy of these two kinds of systolic murmur.

The sounds in a protodiastolic gallop-rhythm are recorded in Fig. 61. Observe that the third tone lies closer to the preceding second sound than it does to the following first sound. The times as actually measured are 0.17 and 0.21 seconds respectively.

As Weiss suggests, we may expect to learn something later on by simultaneous recording of electrocardiograms and phonocardiograms.

THE TELEPHONE STETHOSCOPE.

Very recently a highly ingenious device in the form of a telephonic stethoscope has been invented by S. G. Brown. It depends upon the application of a telephone relay, which in turn is based upon the modern researches of physicists concerning the flow of electrons across a microscopic air-gap between two conducting surfaces at different potentials. Telephonic currents passing through the relay have their strength increased almost twenty-fold, and apparently still greater intensifications may be obtained by placing two relays in tandem, by which the intensification becomes four-hundred-fold.

In the electrical stethoscope, a diagrammatic view of which is reproduced in Fig. 62, the sound of the heart beat is, with

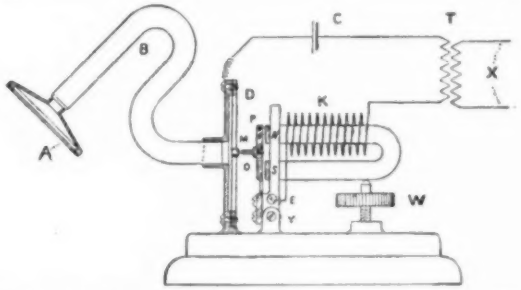

FIG. 62.—Diagrammatic view of Browne's telephonic stethoscope (by courtesy of Scientific American, 1910, CII, Fig. 4).

the aid of a transformer, intensified about 60 times. The study of pathological cases with this instrument has been begun in the London Hospital, where, it is said, the physicians are much pleased with its promise.

"Long-distance" auscultation of the heart and lungs is now feasible. Brown's instrument can be attached to the long-distance telephone service; by means of it the heart sounds of a person in London have already been listened to, and heard distinctly, by physicians in the Isle of Wight—a distance of about 100 miles.

I see no reason why this instrument should not be combined with a graphophone and permanent records be made of heart sounds; they might then be reproduced at will before medical societies or classes in physical diagnosis. Weiss has reproduced mechanically recorded heart-sounds with the help of a telenium-cell, battery and telephone.

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NOTES AND NEWS.

ADDITIONAL HUMAN EMBRYOS.

Professor Mall, of the Johns Hopkins University, again requests that physicians send him embryological specimens which are constantly falling into their hands. The collection of such specimens at the Johns Hopkins Medical School is now one of the best in existence, has been studied carefully by the staff here, and is being used constantly by anatomists at home and abroad. About 100 published studies on human embryology are based upon this collection, including the "Manual of Human Embryology" in two volumes, published recently by the J. B. Lippincott Co.

Much more material than is now at hand is needed by investigators to further the science of human embryology as well as to study with greater care the diseases of the ovum and the cause of abortion. To make material of greatest value it should be preserved immediately after the abortion in a 10 per cent solution of formalin, or by more refined methods, if they are at hand. Small specimens should not be dissected, but should be preserved entire in formalin. Of very great value are good histories of the cases, for through them we may discover the cause of abortions, and ultimately their cure. Studies of this kind enable embryologists to be of use to physicians in active practice. Specimens should be packed in bottles filled *completely* with the preserving fluid, and not wrapped in cotton. If there are no air spaces in the bottle, no amount of shaking will injure the most delicate embryo. Small specimens may be sent by mail, while larger ones should be sent by express, collect charges, to

DR. F. P. MALL,
Johns Hopkins Medical School, Baltimore, Md.

THE JOHNS HOPKINS HOSPITAL BULLETIN.

The Hospital Bulletin contains details of hospital and dispensary practice; abstracts of papers read and other proceedings of the Medical Society of the Hospital, reports of lectures, and other matters of general interest in connection with the work of the Hospital. It is issued monthly. Volume XXI is now in progress. The subscription price is $2.00 per year.

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